

# H.E.S.S. Observations of the Galactic Center region

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(HEPL/Stanford University)

for the H.E.S.S. collaboration

*(special thanks to Loïc Rolland & Jim Hinton)*



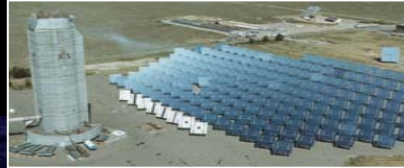
GLAST Mini-symposium on the Galactic Center Region

# VHE Astronomy World

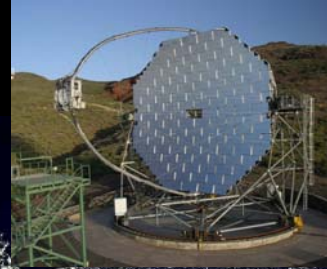
MILAGRO



STACEE



MAGIC



TIBET



MILAGRO

STACEE

MAGIC

TACTIC

TIBET  
ARGO-YBJ

PACT

VERITAS

VERITAS



HESS

HESS



TACTIC



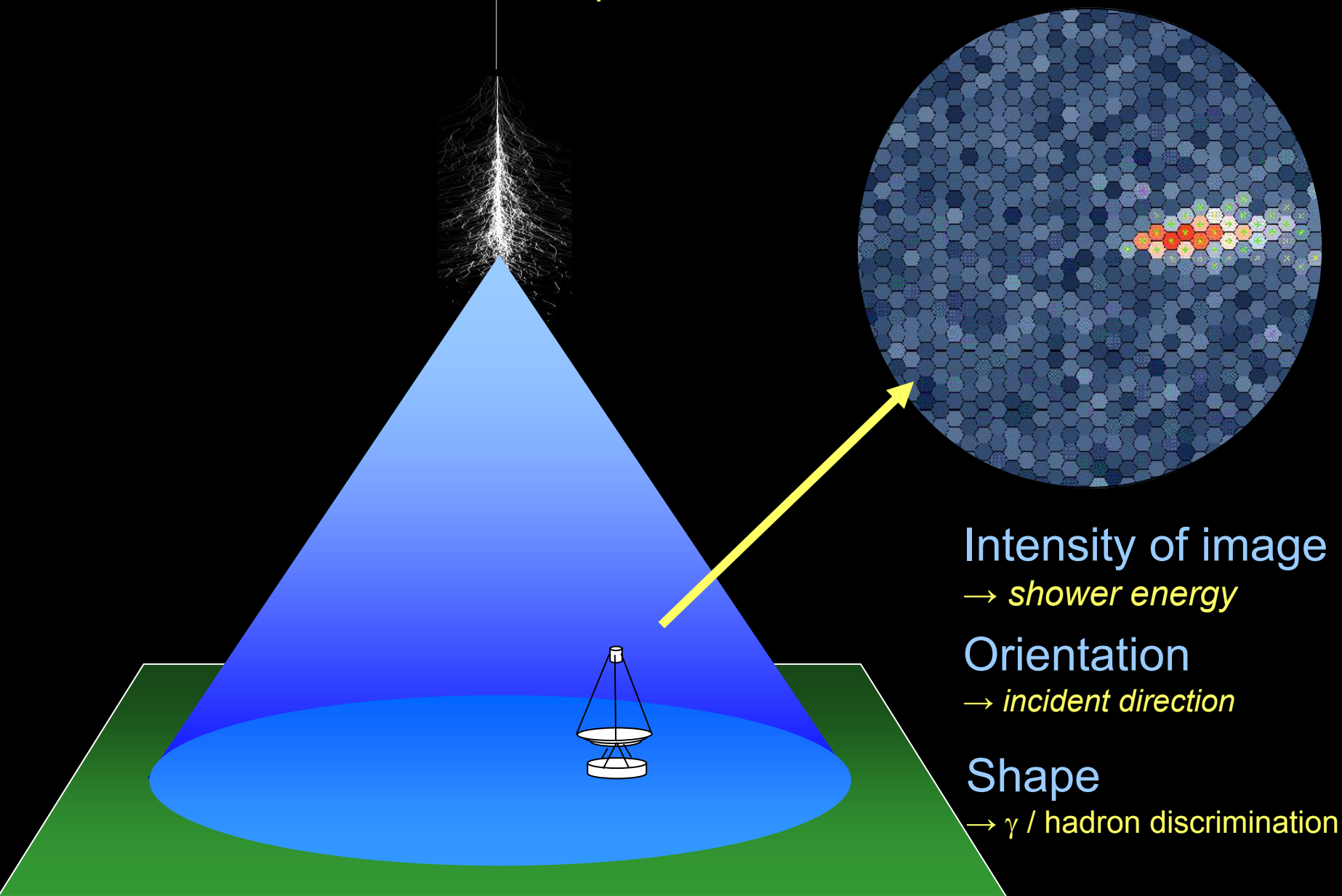
CANGAROO III

CANGAROO



# Imaging Atmospheric Cherenkov Telescopes

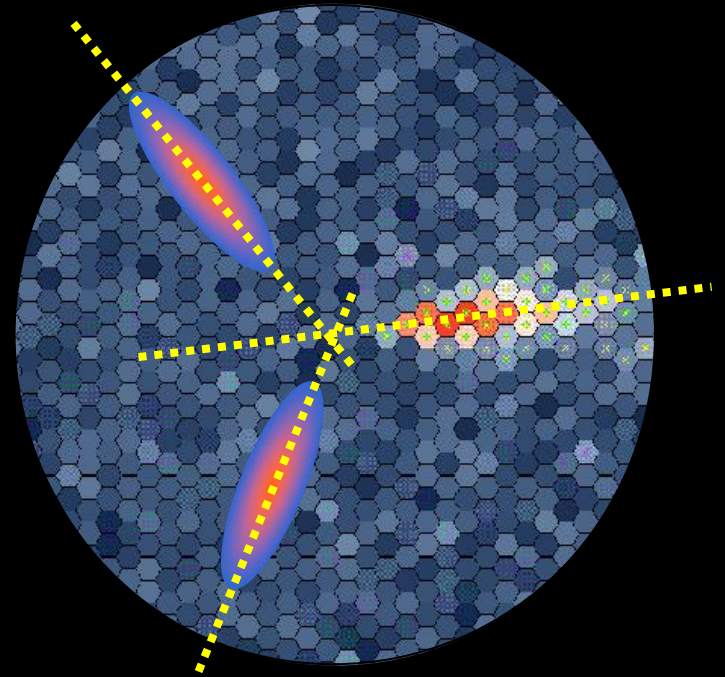
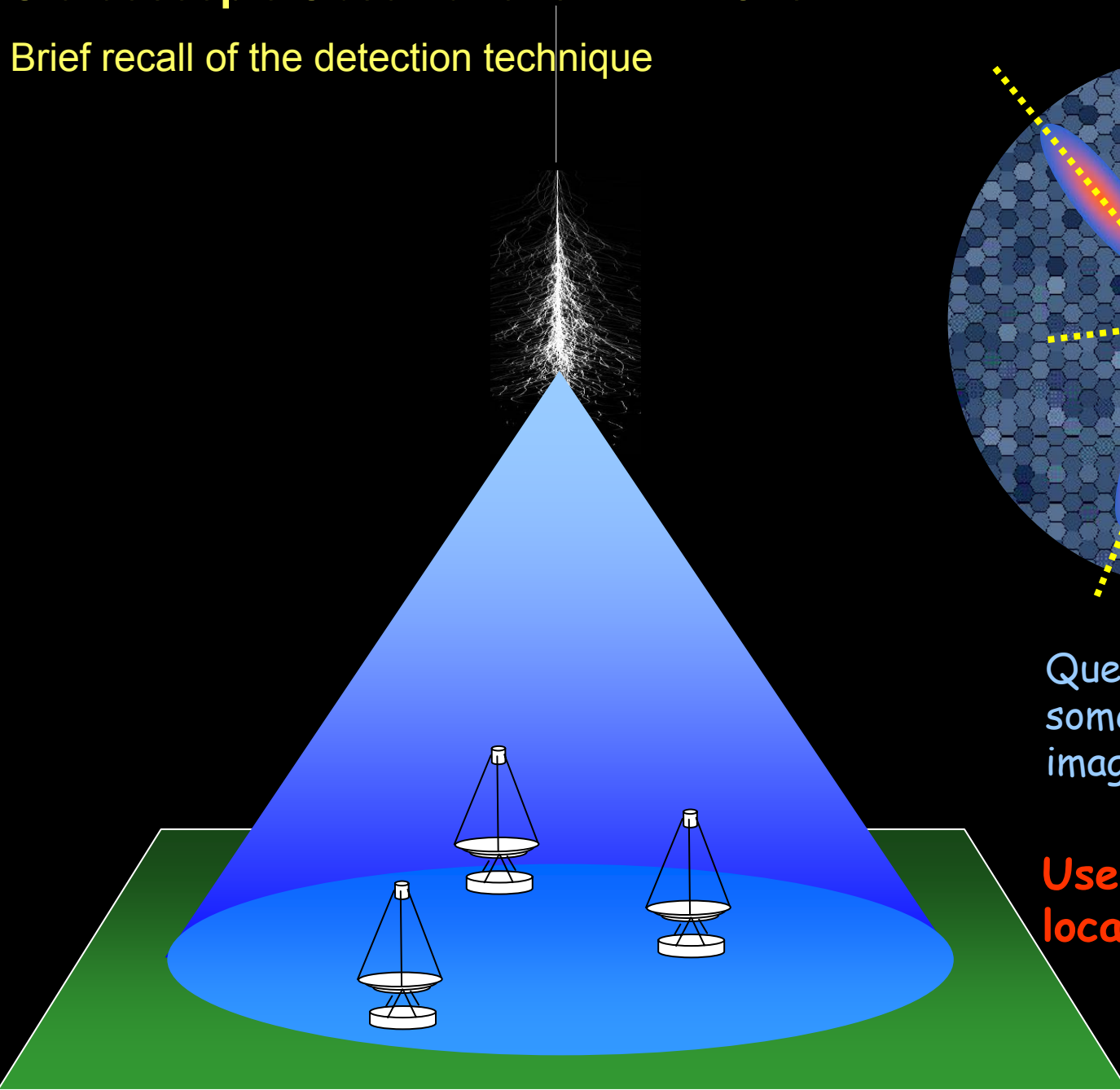
Brief recall of the detection technique





# Stereoscopic Observations with IACTs

Brief recall of the detection technique



Quest: Source is located  
somewhere along the  
image of shower axis ...

**Use more views to  
locate source!**

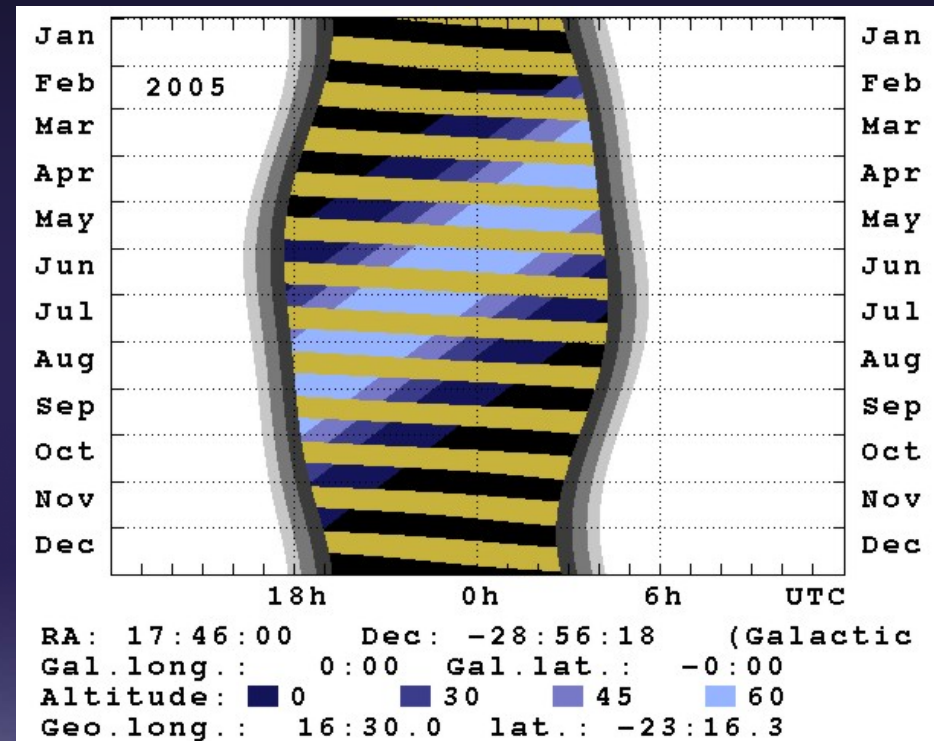
One of the key scientific drivers and de facto a requirement for the H.E.S.S. observation site is access to the Galactic Center region under most favourable observing conditions!

**high zenith angle** observation

→ low energy threshold

**low zenith angle** observation one gets for free once succeeded in convincing the obs time committee

→ maximize statistics at the TeV end of source spectrum



# High Energy Stereoscopic System

Four telescopes,  
107 m<sup>2</sup> mirror area each

4 x 960 PMT cameras,  
field of view 5°

Observation in moonless  
nights, ~1000 h / year

Each night several objects  
are tracked and ~300  
images recorded per  
second

First analysis (almost)  
online in the same night  
on cluster in Namibia

Final analysis and  
calibration in Europe

**Sensitivity:**  
**1% Crab in 25 h**

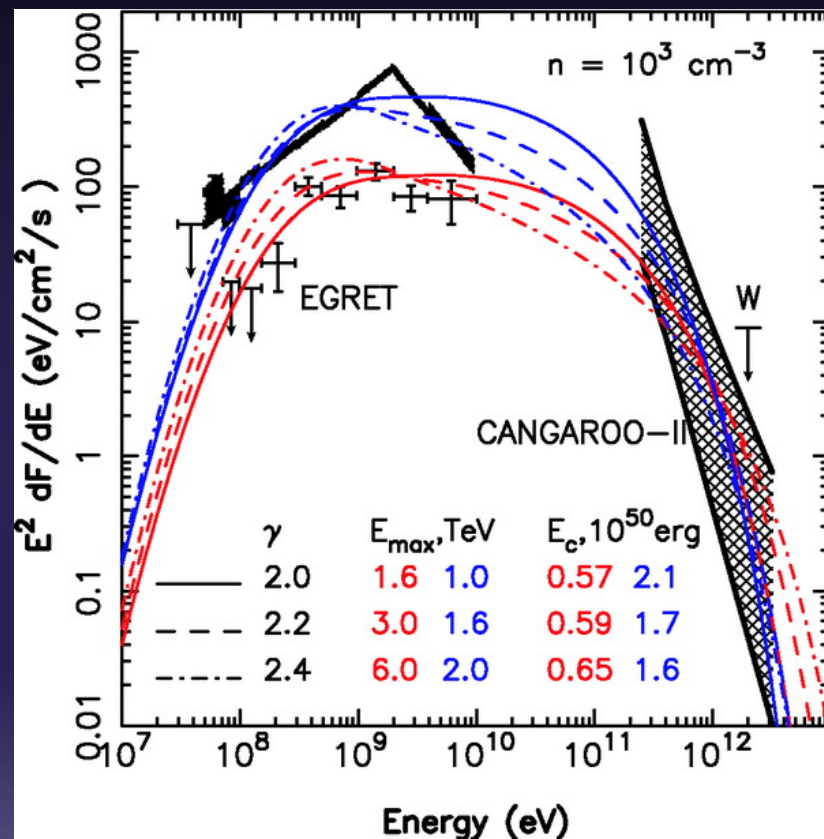
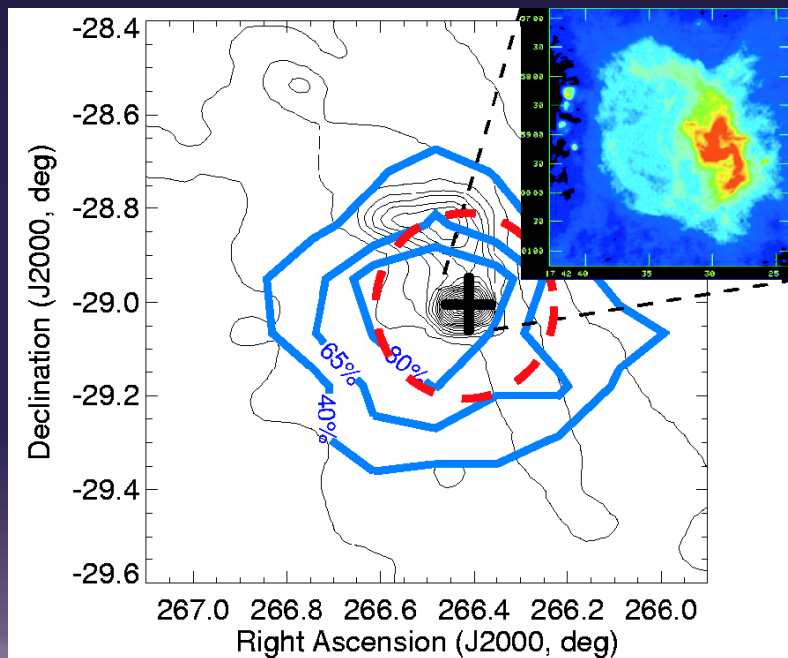




# The VHE Source in Galactic Center region

## (i) pre-H.E.S.S. observations

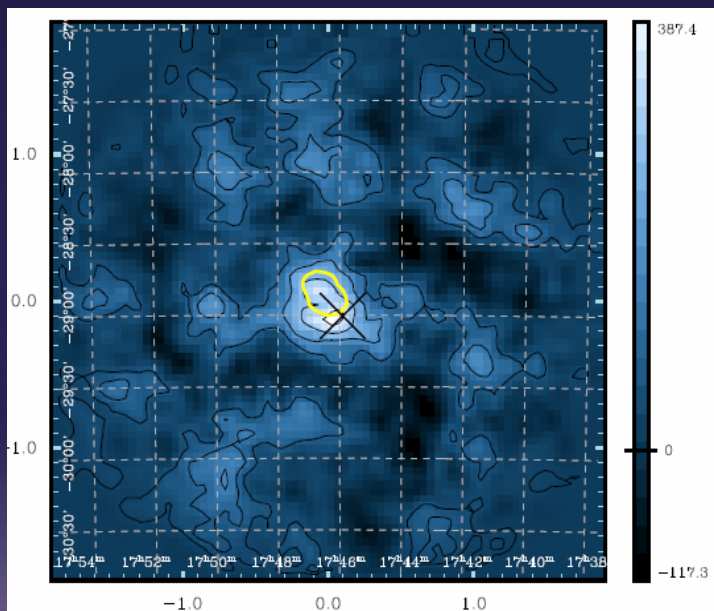
Cangaroo II, HZA  
 67 hours in '01 and '02  
 Tsuchiya et al. 2004: -4.6 spec. index,  
 connection to 3EGJ1746-2851



# The VHE Source in Galactic Center region

## (i) pre-H.E.S.S. observations

Whipple telescope, LZA  
26 hours between '95 and '03  
Kosack et al. 2004: 3.7 sigma,



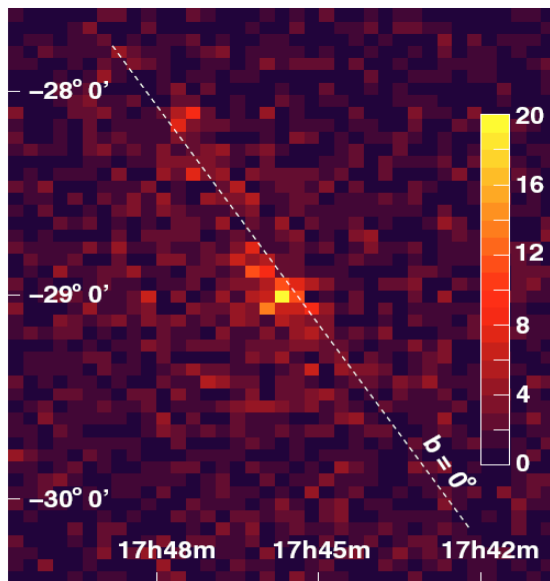
“While a typical galactic source such as a supernova remnant, pulsar, or stellar mass black hole is unlikely, an association with SgrA\* is still a viable possibility, and the detection of correlated variability in future gamma-ray and X-ray observations could make the identification compelling.”



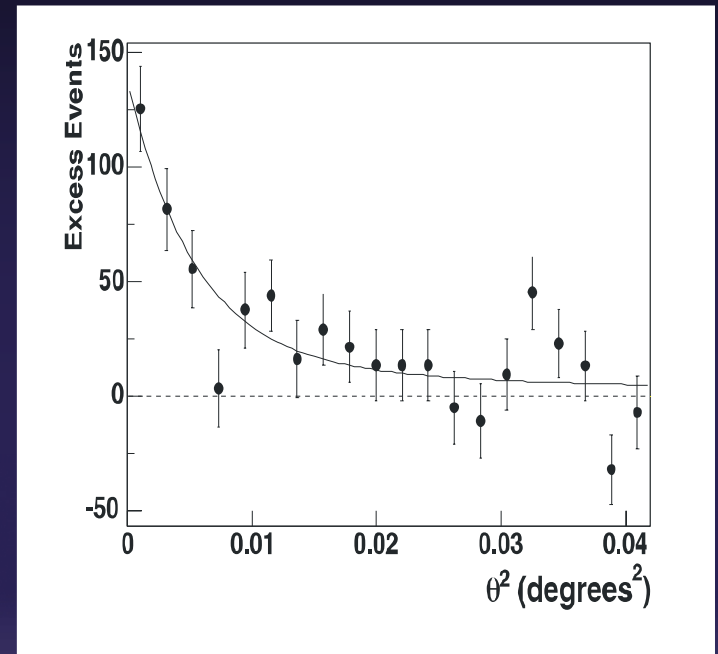


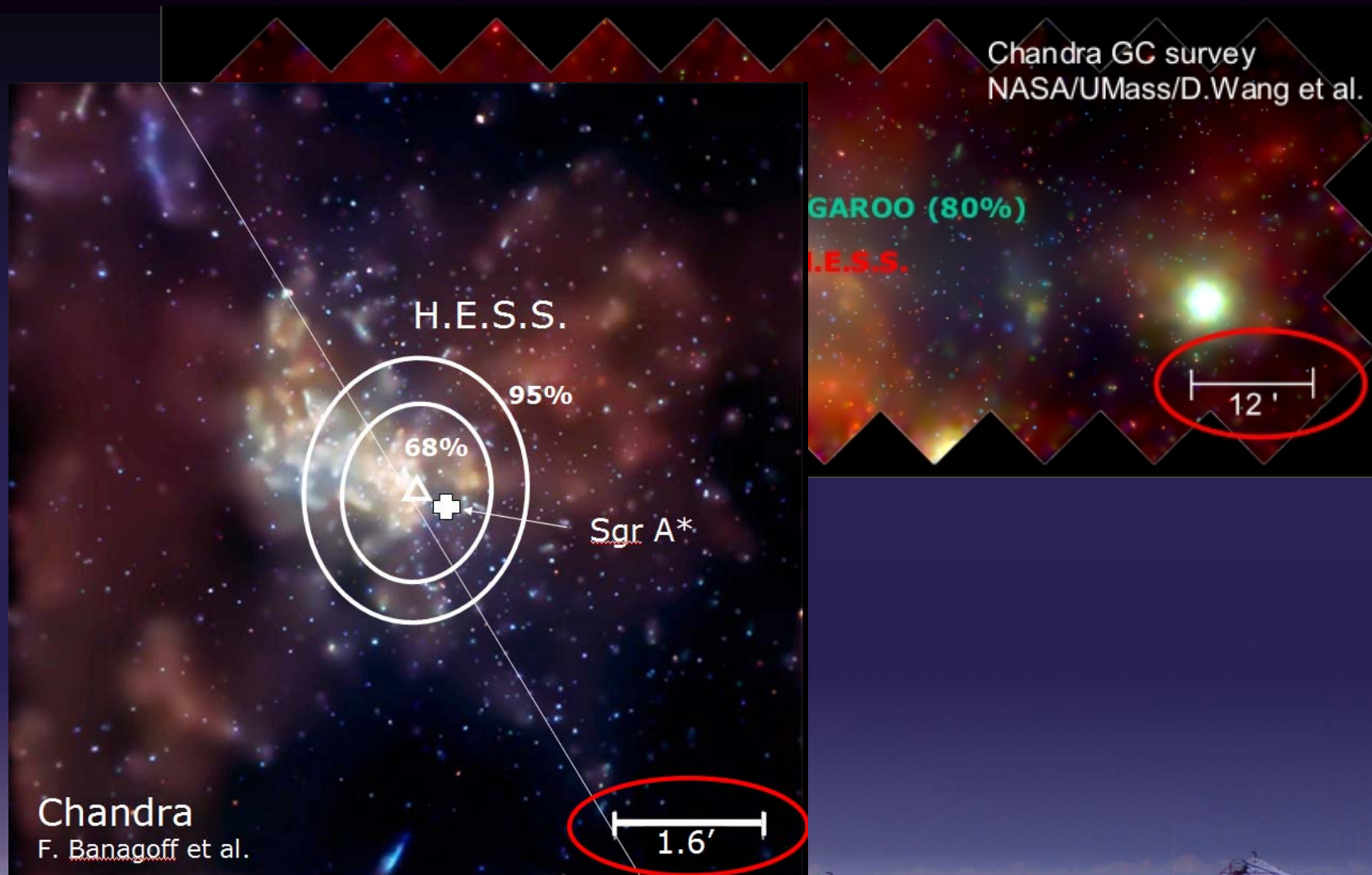
# The VHE Source in Galactic Center region

2003: ~ 16 h of two telescope data, 9.2 sigma, spectrum  
-> Aharonian et al. 2004, A&A Letter



**Fig. 1.** Angular distribution of  $\gamma$ -ray candidates for a  $3^\circ$  field of view centred on Sgr A\*. Both data sets (“June/July” and “July/August”) are combined, employing tight cuts to reduce the level of background. The significance of the feature extending along the Galactic Plane is under investigation.



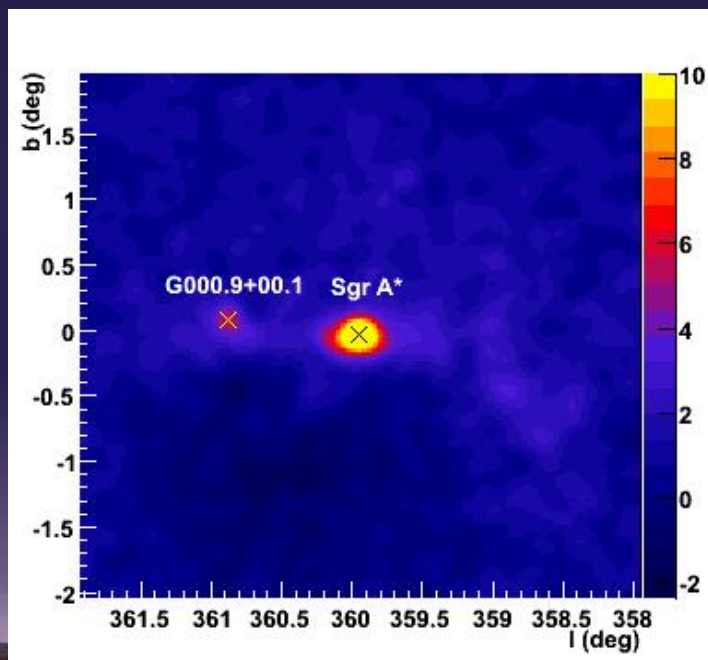


# The 2004 observations on HESS J1745-290

48 hours live time from March 30 to September 4, 2004

pointing within 2 degrees of Sgr A\*

0° to 60° zenith angle



$\theta < 0.11^\circ$  within Sgr A\*:

- $38 \sigma$
- $1862 \gamma$

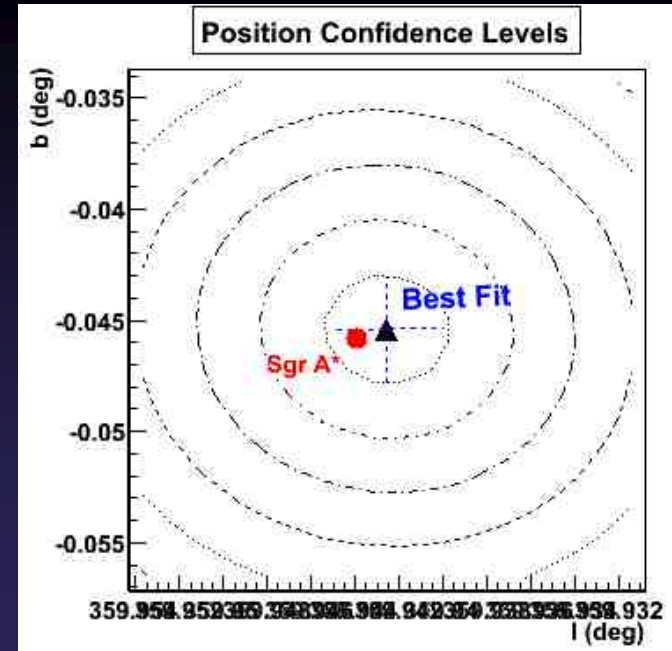




# Position and extension (2004)

Assuming point-like source

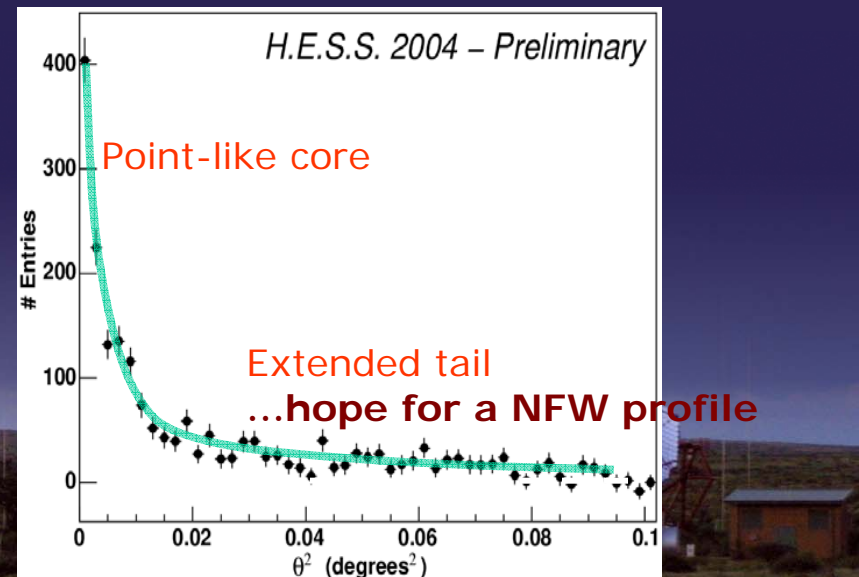
compatible with Sgr A\*  $5.6'' \pm 10'' \pm 20''$



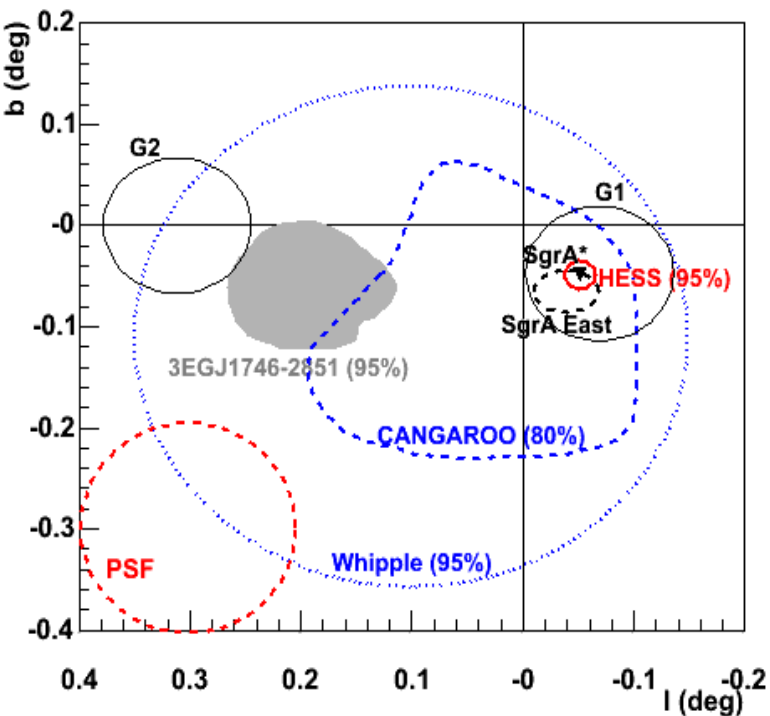
Assuming symmetric gaussian

distance to Sgr A\*  $3.9'' \pm 13'' \pm 20''$

extension:  $1.9' \pm 0.23'$



# Getting into the high-energy picture



Compatibility with

INTEGRAL source (G1)

black hole Sgr A\*

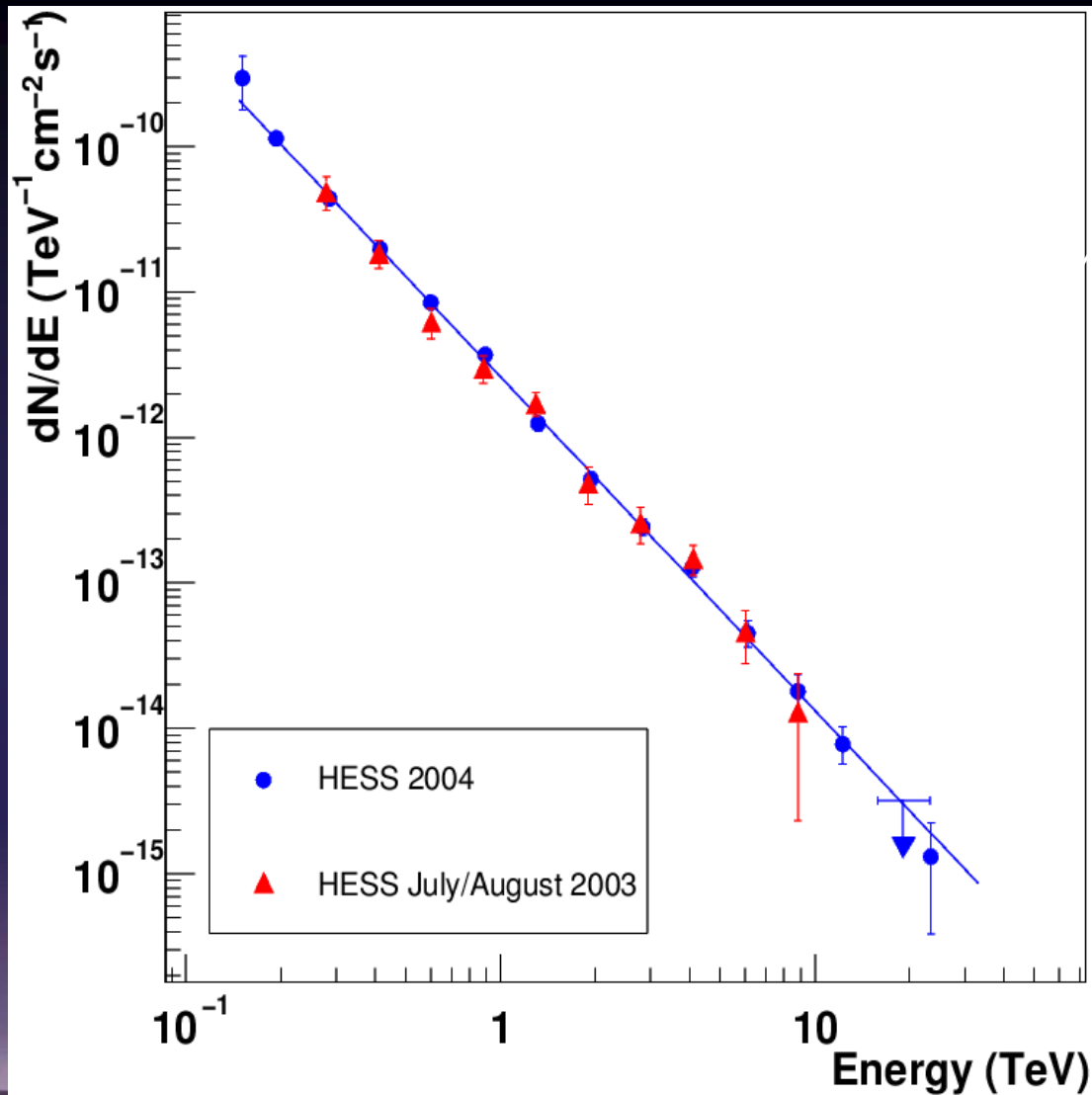
supernova Sgr A East

Incompatibility with

unidentified EGRET source (99%)



# Gamma ray spectrum



Power law,  
index 2.3

No significant  
variability

on year scale

on month scale

on day scale

on hour scale

on minute scale

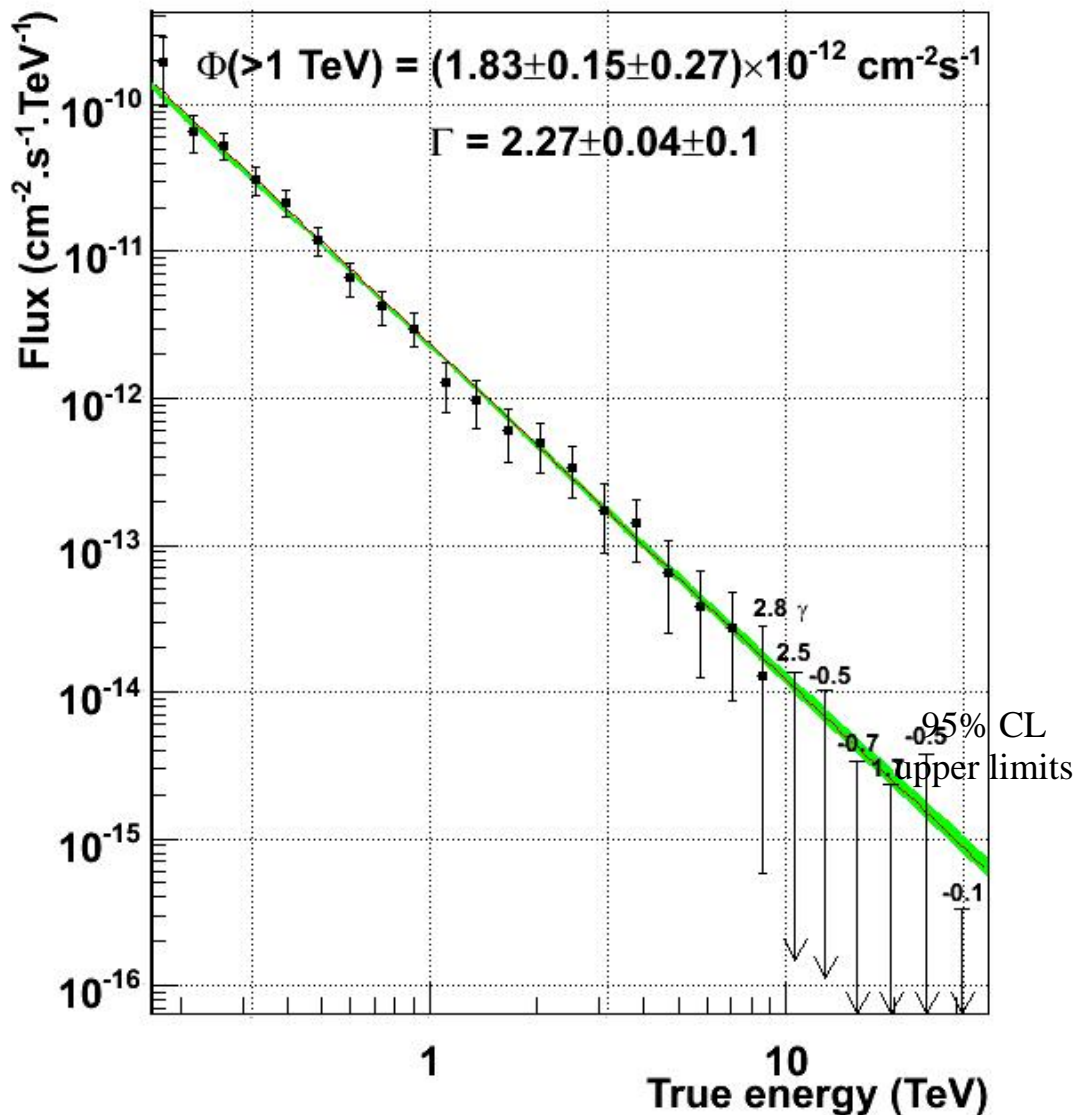
(in  $\sim 40$  h obs. time

distributed over 2 years)





# Gamma ray spectrum, the closer look



Energy range:

166 GeV-37 TeV

Compatible with 2003 spectrum:

$\Gamma = 2.2 \pm 0.09 \pm 0.15$

$\Phi(>1 \text{ TeV}) = (2.0 \pm 0.4 \pm 0.3) \times 10^{-12} \text{ cm}^{-2} \text{ s}^{-1}$

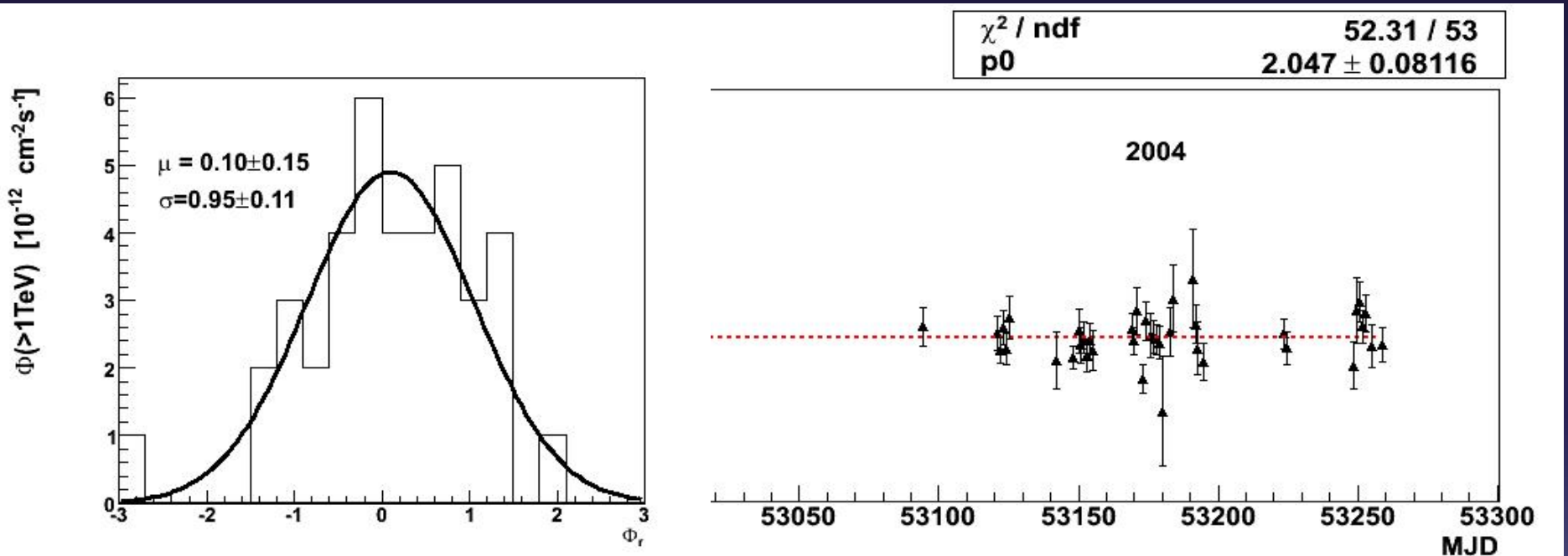
Search for exponential cut-off:

$E_{\text{cut}} > 6 \text{ TeV (95\% CL)}$



# Variability?

Nightly average flux  
15% systematic errors added



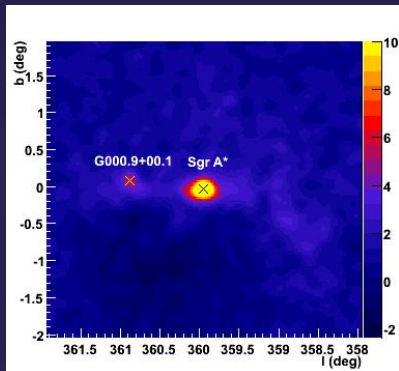
38  $\sigma$  detection of  
HESS J1745-290  
in 2004

Position compatible  
with Sgr A\* within 6"

Slightly extended ?  
 $\sim 1.9'$

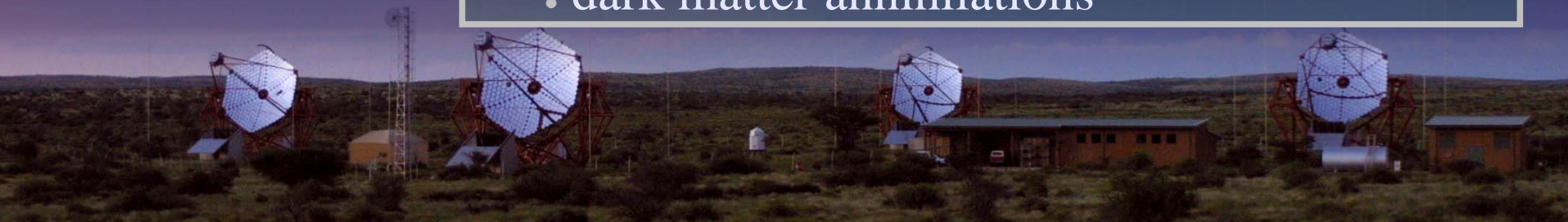
Uncurved power law spectrum  
 $\Gamma = 2.27$

No indication for  
variability in 2003-2004



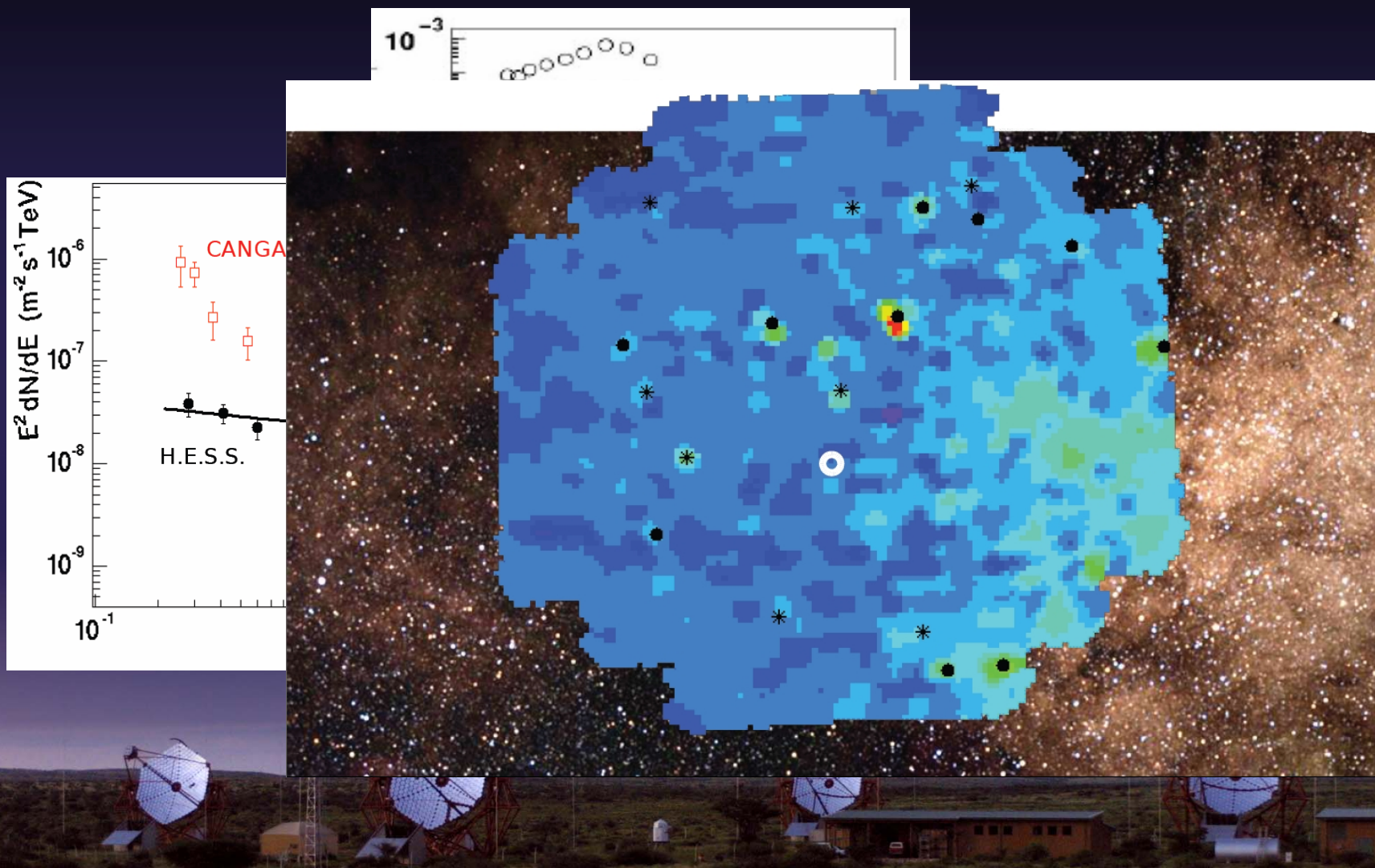
Possible origin for the  $\gamma$ -rays:

- Sgr A\*
- Sgr A East
- stellar wind collisions
- cosmic-ray interactions in the dense medium
- dark matter annihilations

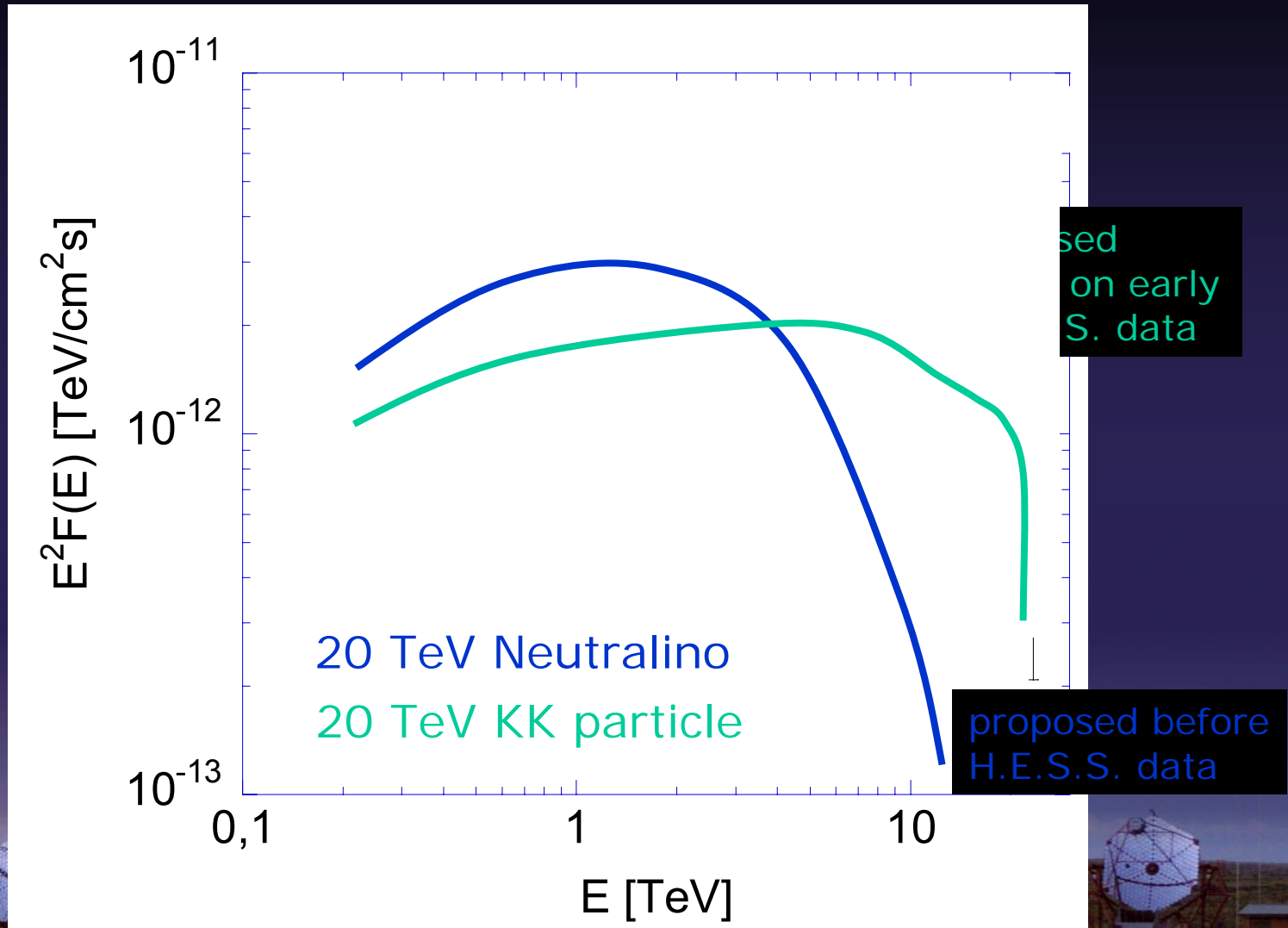




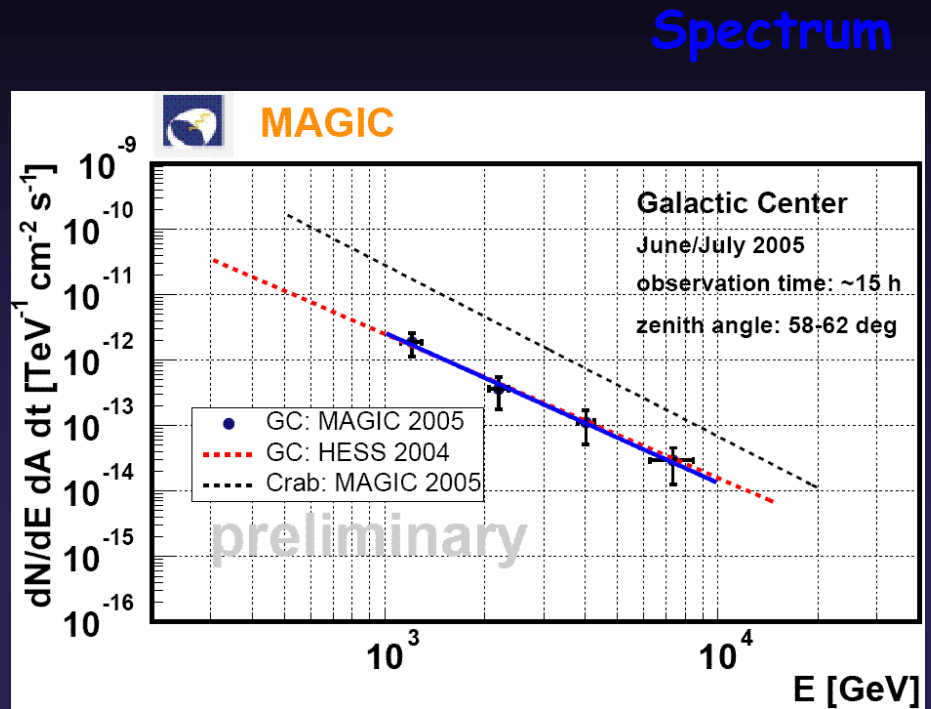
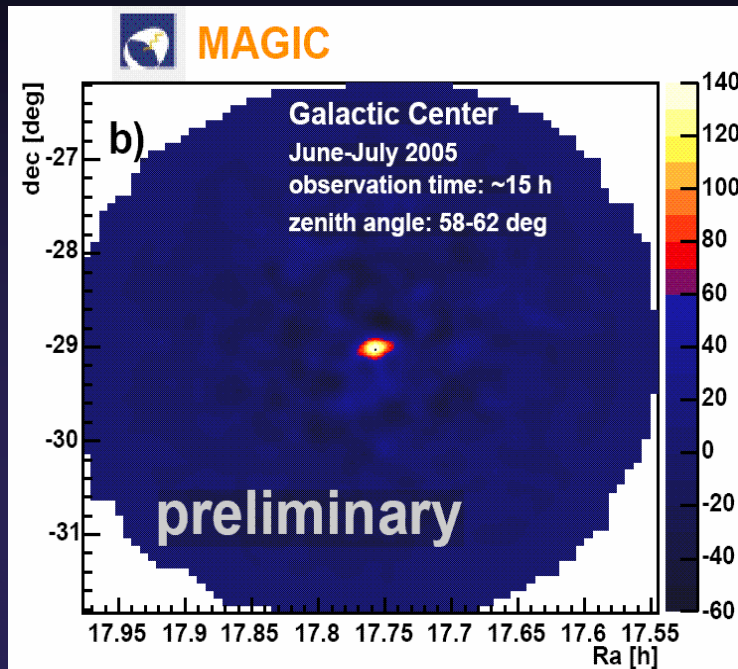
# The apparent inconsistency between Cangaroo/H.E.S.S. spectra



# Theories evolve, too!



# Galactic Center clearly seen by MAGIC



ICRC'05

Very assuring spectral agreement between  
H.E.S.S. and MAGIC!



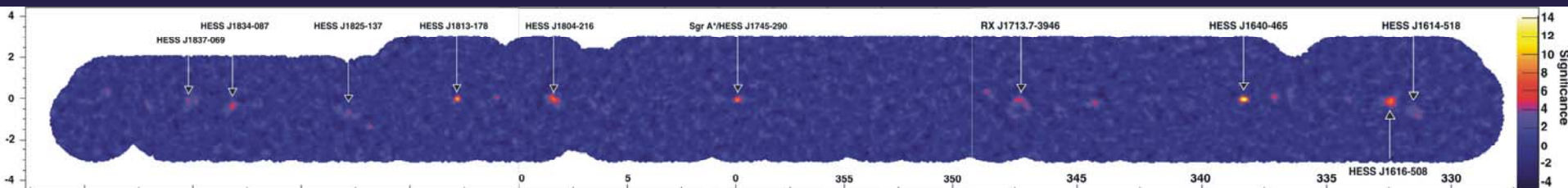


# ...towards diffuse VHE emission from the GC

beyond the GC point source:

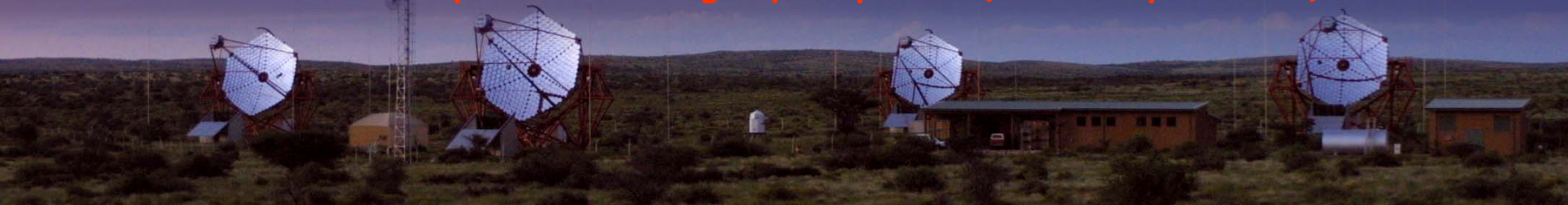
H.E.S.S. has documented that scans are possible and indeed successfully

-> perfectly understood instrument response, intelligent observation strategy, strict cut and data quality management

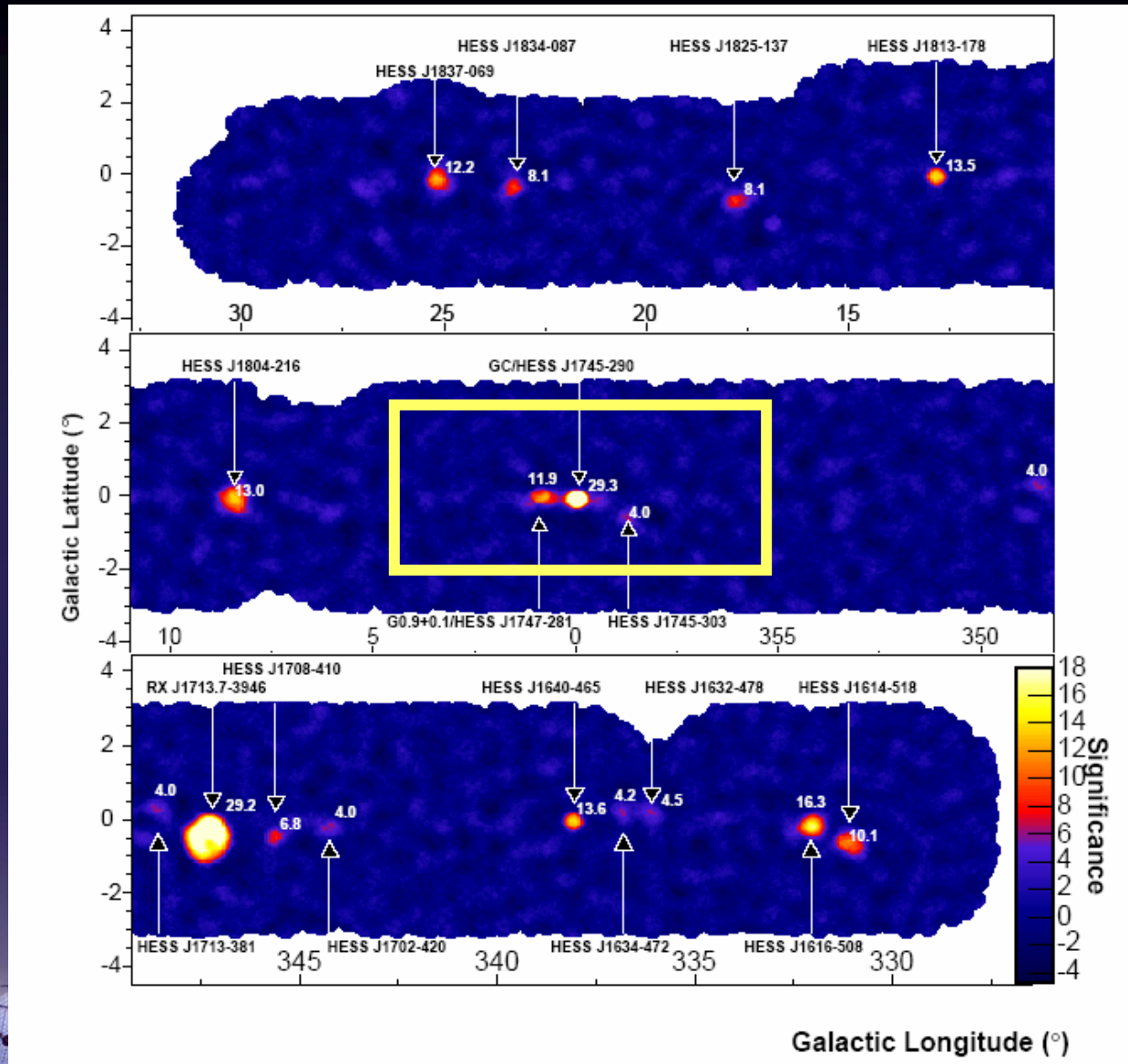


As a result of the dedicated and the scan observations,  
sufficient exposure in GC region accumulated to go further now!

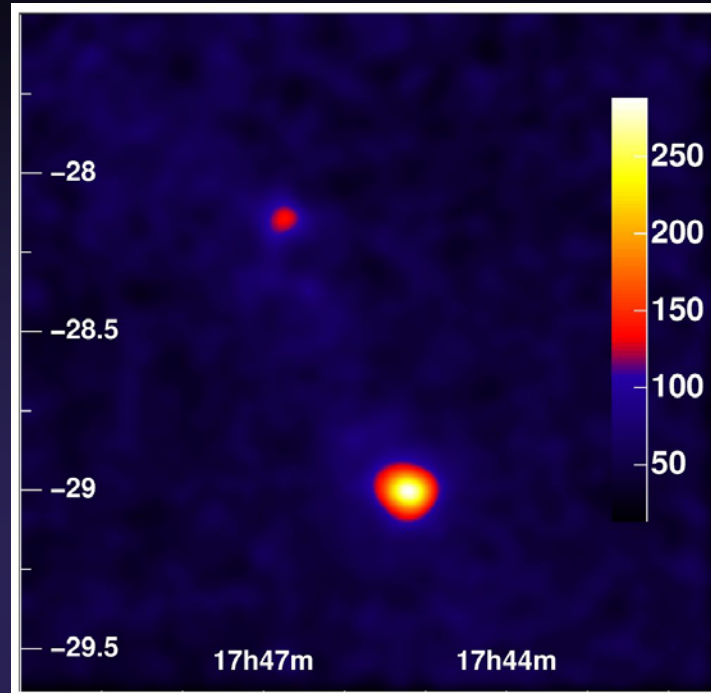
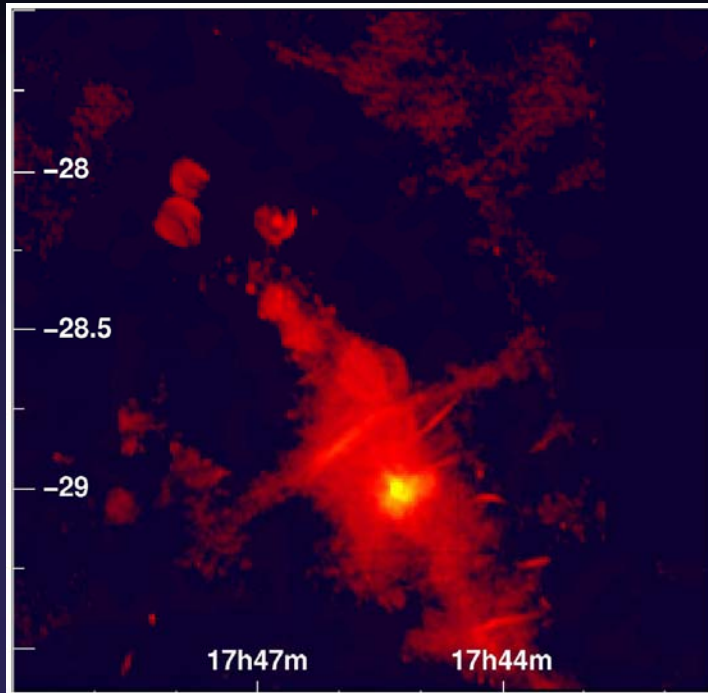
-> achieved by 2004 with high-quality data (4 telescope stereo)



# The 1<sup>st</sup> leg of the Galactic Plane Scan completed → Science Magazine, 2005



# The Galactic Center region



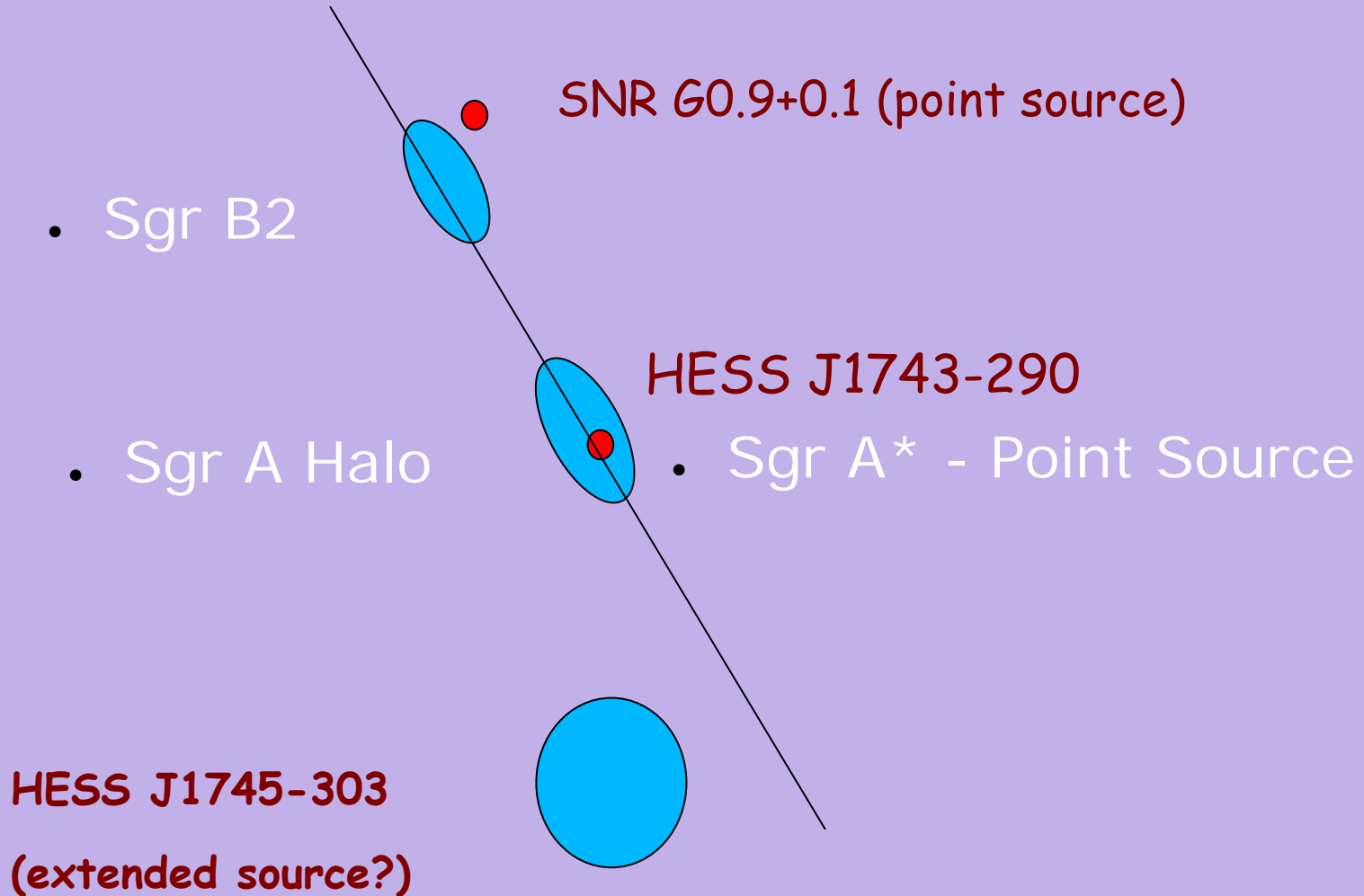
## OUTLINE:

- point source removal HESS J1745-290 (Sgr A[\*]/East]), G0.9+0.1
- investigate residual
- gas dist. in GC region  $\rightarrow$  more meaningful tracer here: CS  $J=1-0$

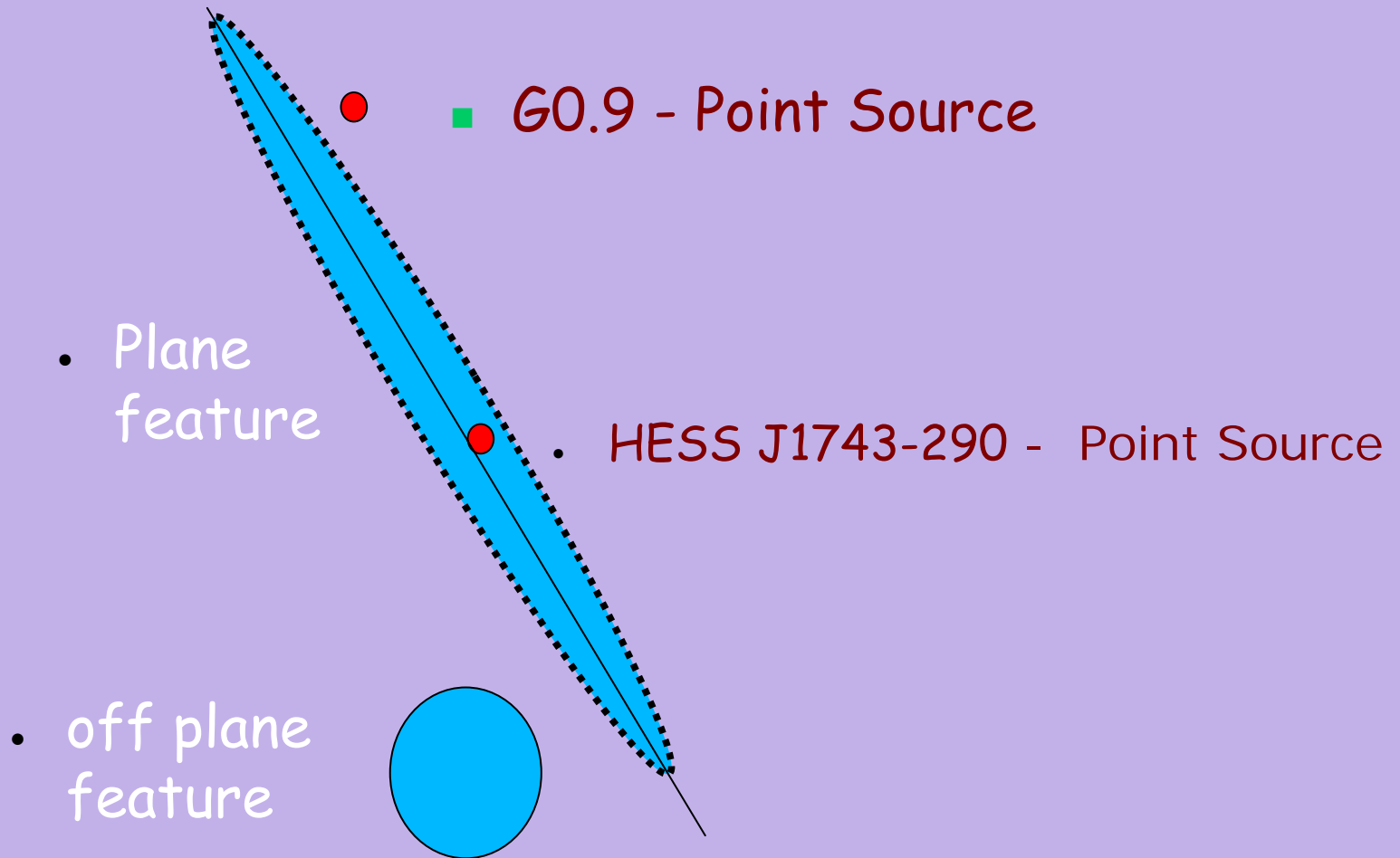




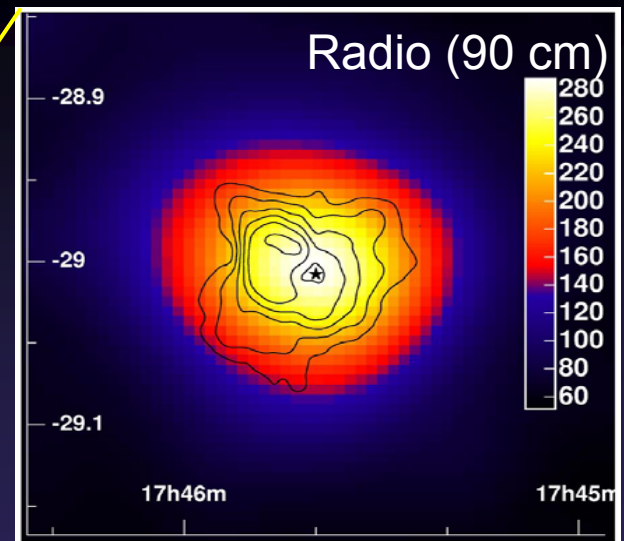
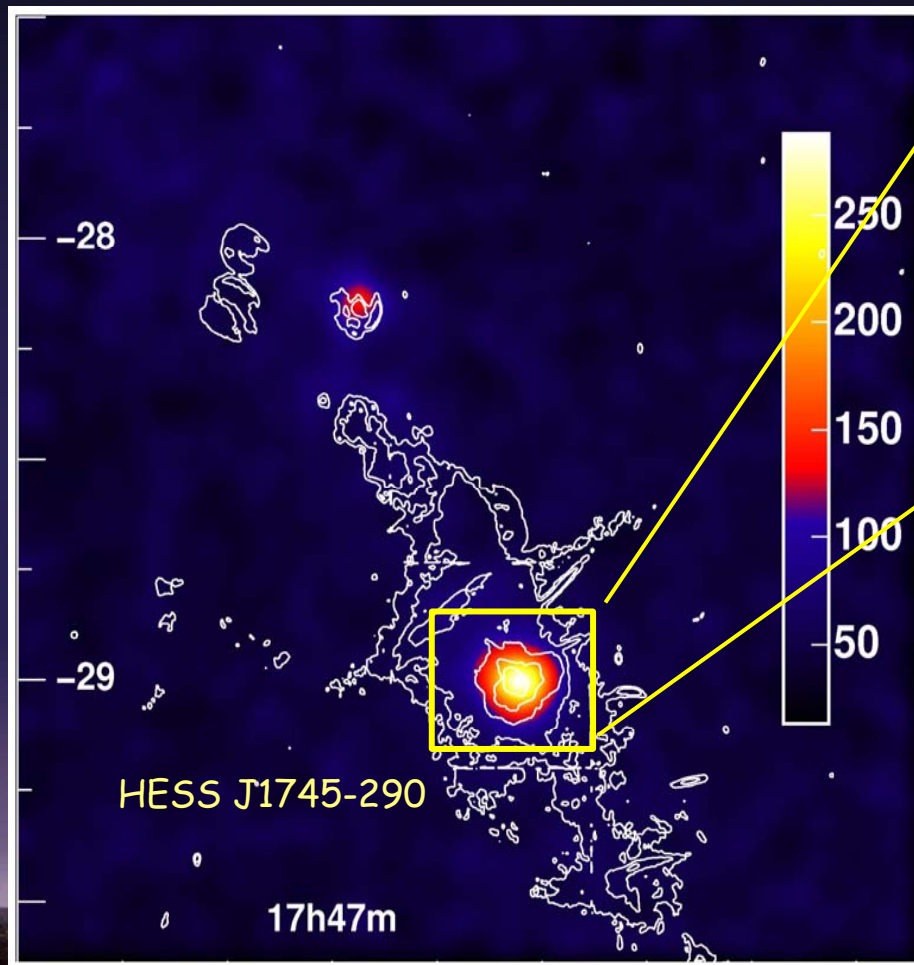
# What features exist?



or...



# The dominant source

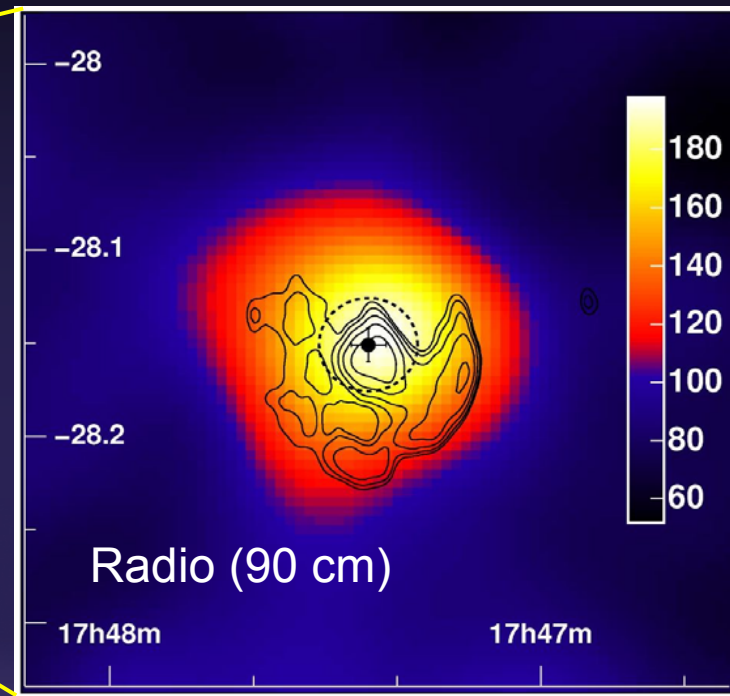
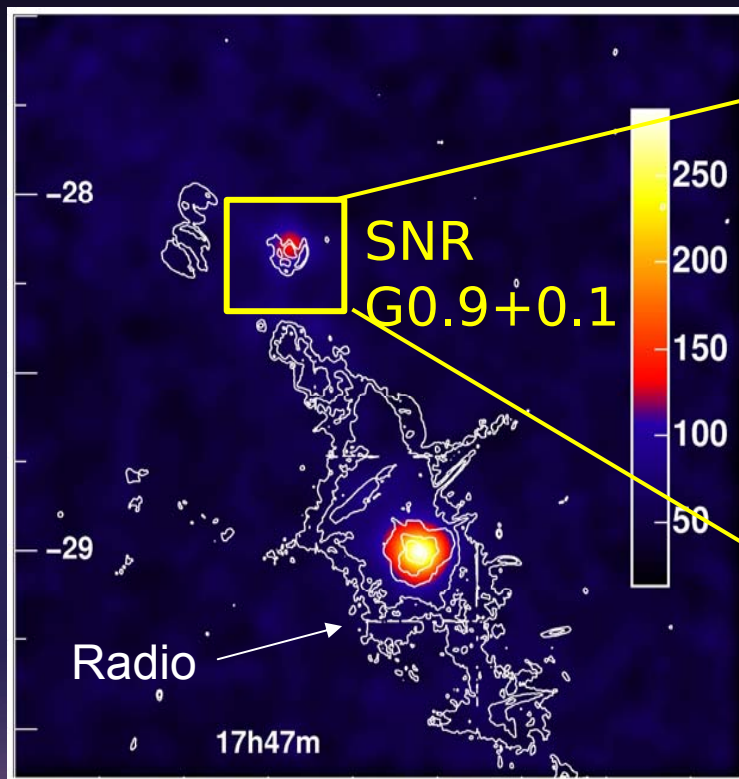


38  $\sigma$ ,  
nonvariable,  
perhaps marginally extended  
source





The second source in the region:  
A SNR/PWN association:  $G0.9+0.1$



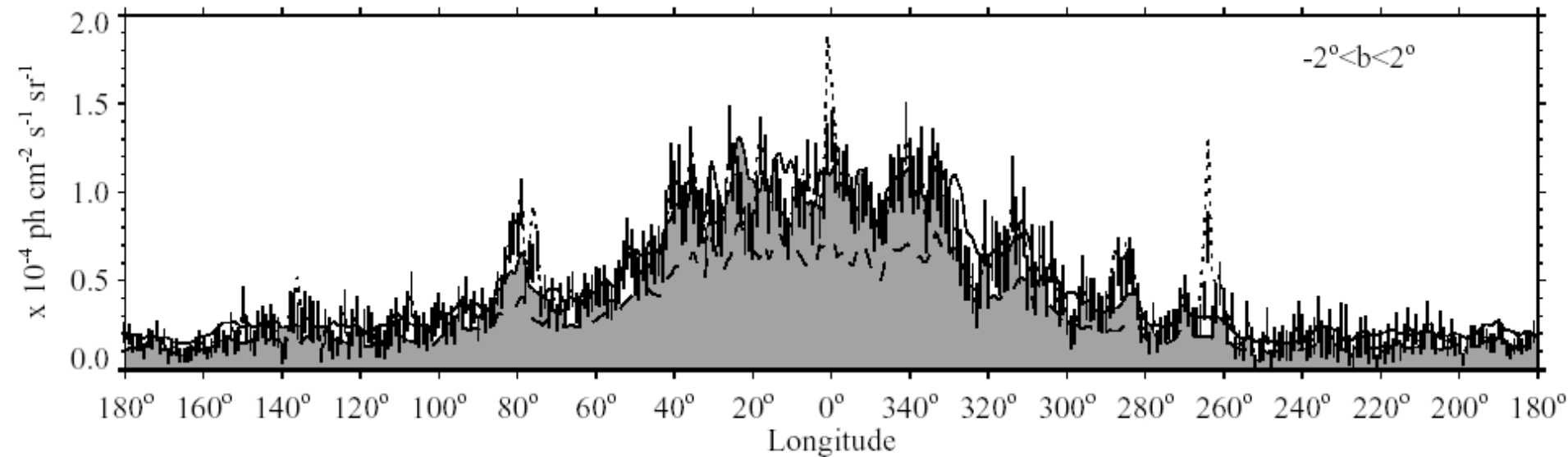
2004: 50 hrs, 4 Telescopes,  $13 \sigma$

Consistent with point source  
at position of PWN  
(but not SN shell).  
2% Crab flux (50% luminosity).

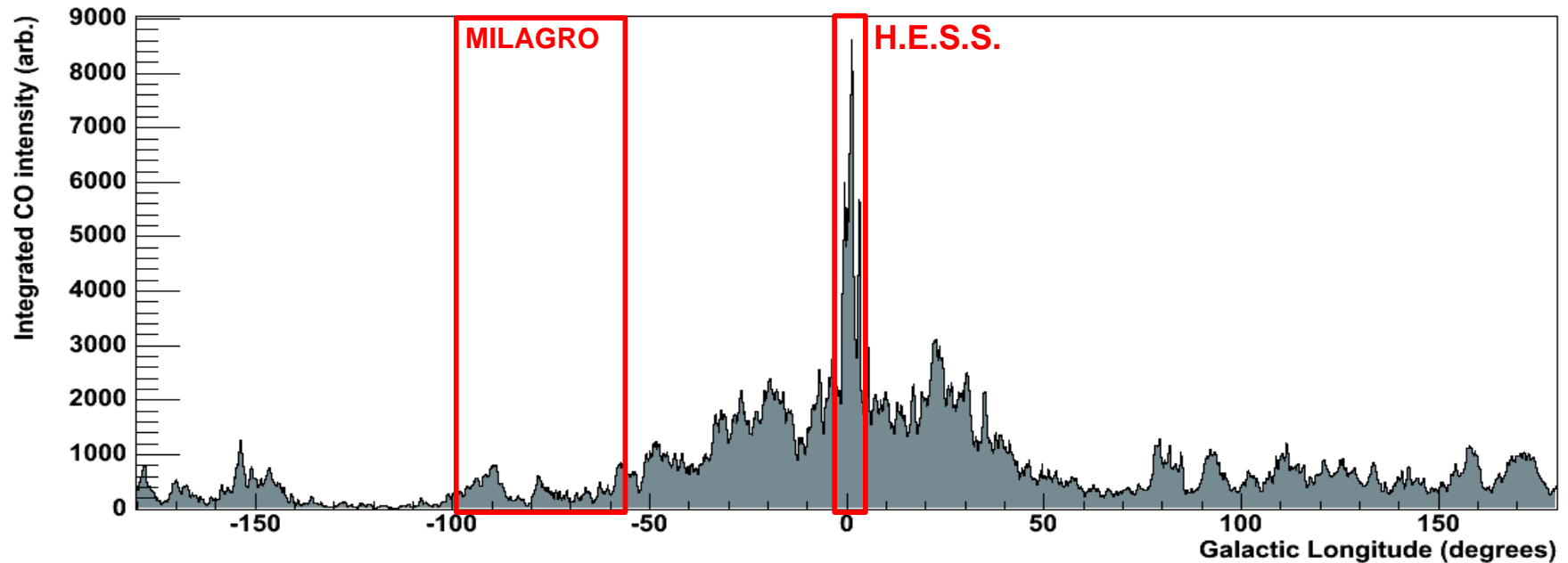


# Diffuse $\gamma$ -Rays from Cosmic Rays

Cosmic ray interactions with the ISM medium lead to gamma-ray production via  $\pi^0$  decay (+ bremsstrahlung, IC, secondaries ...)  
eg EGRET ( $\sim 100$  MeV):



# Molecular Material in the Galaxy

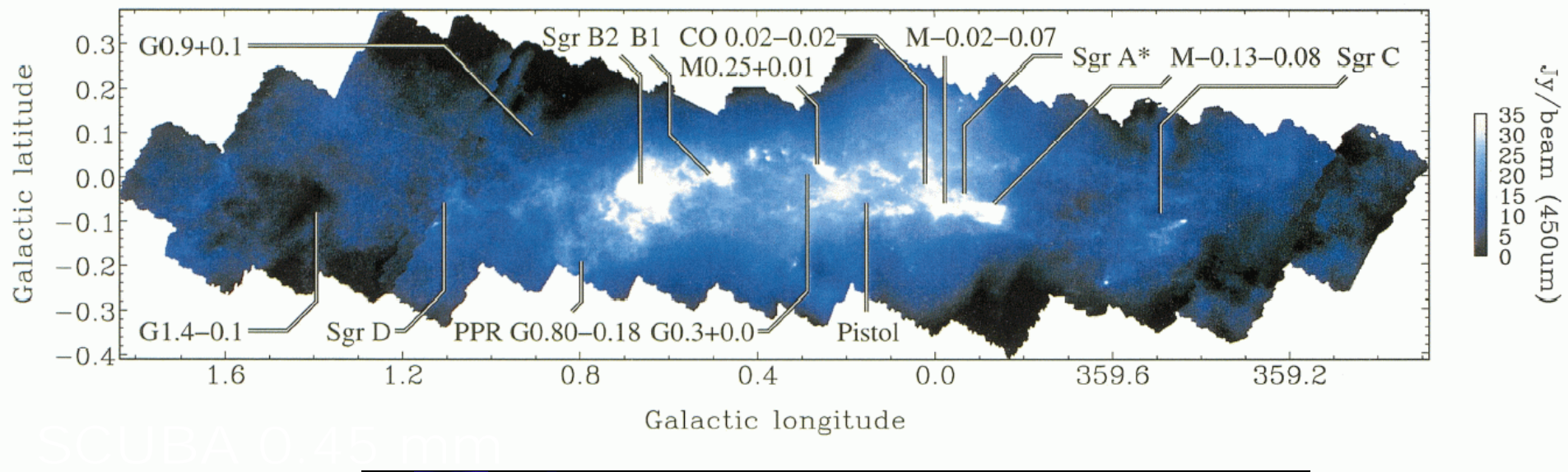


- Atomic component is rather uniform
- Molecular part (traced by CO) is strongly peaked along the plane and in the GC region



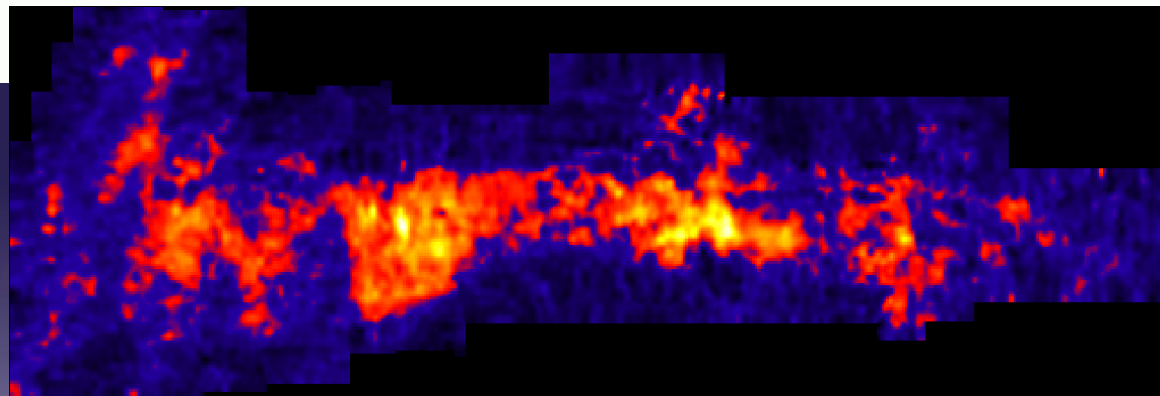


# Dust and Molecules in the GC



SCUBA 0.45 mm

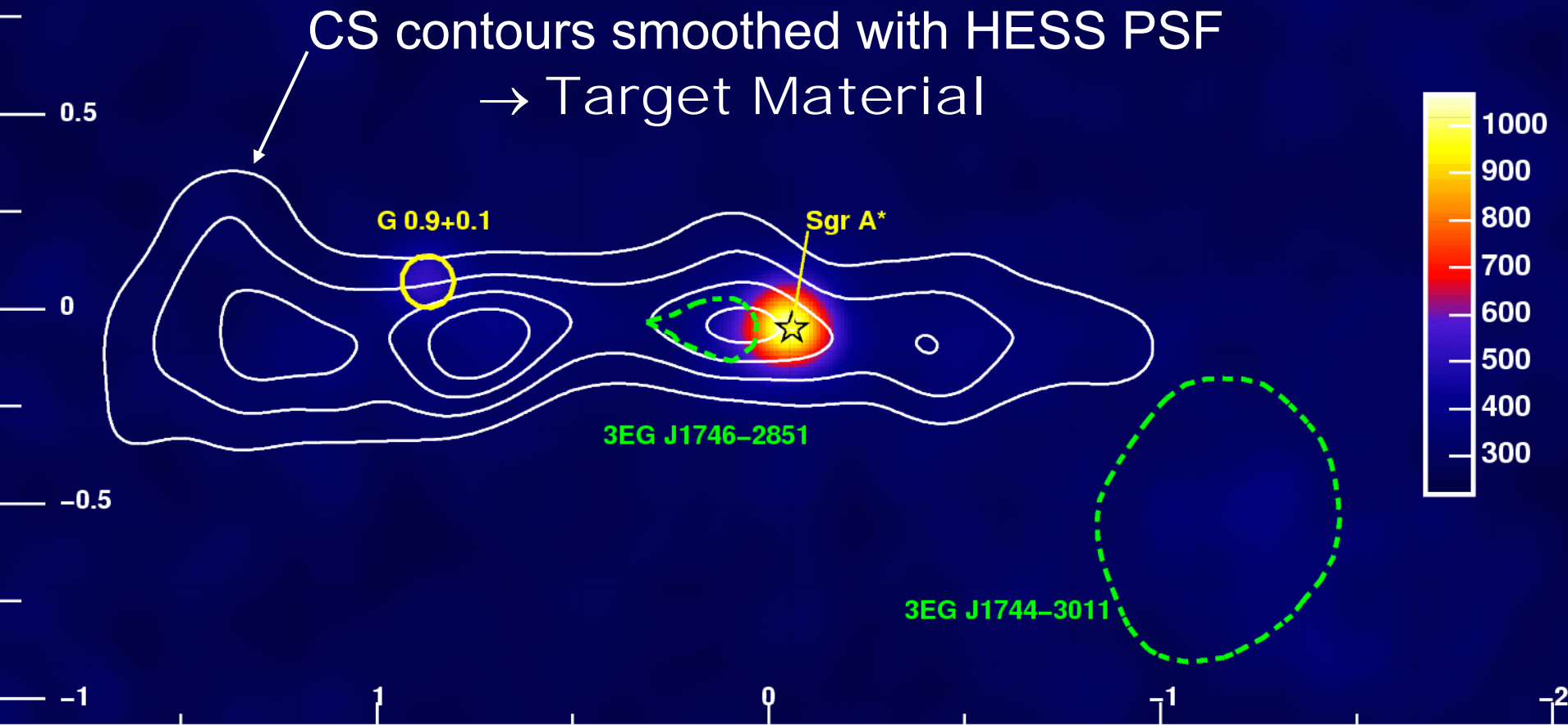
**C<sup>32</sup>S Line  
Emission**  
 $J = 1 - 0$   
(~49 GHz)



**50 million solar masses in (dense) molecular clouds in  
the central 300 parsecs**



# Diffuse $\gamma$ 's in H.E.S.S. data?

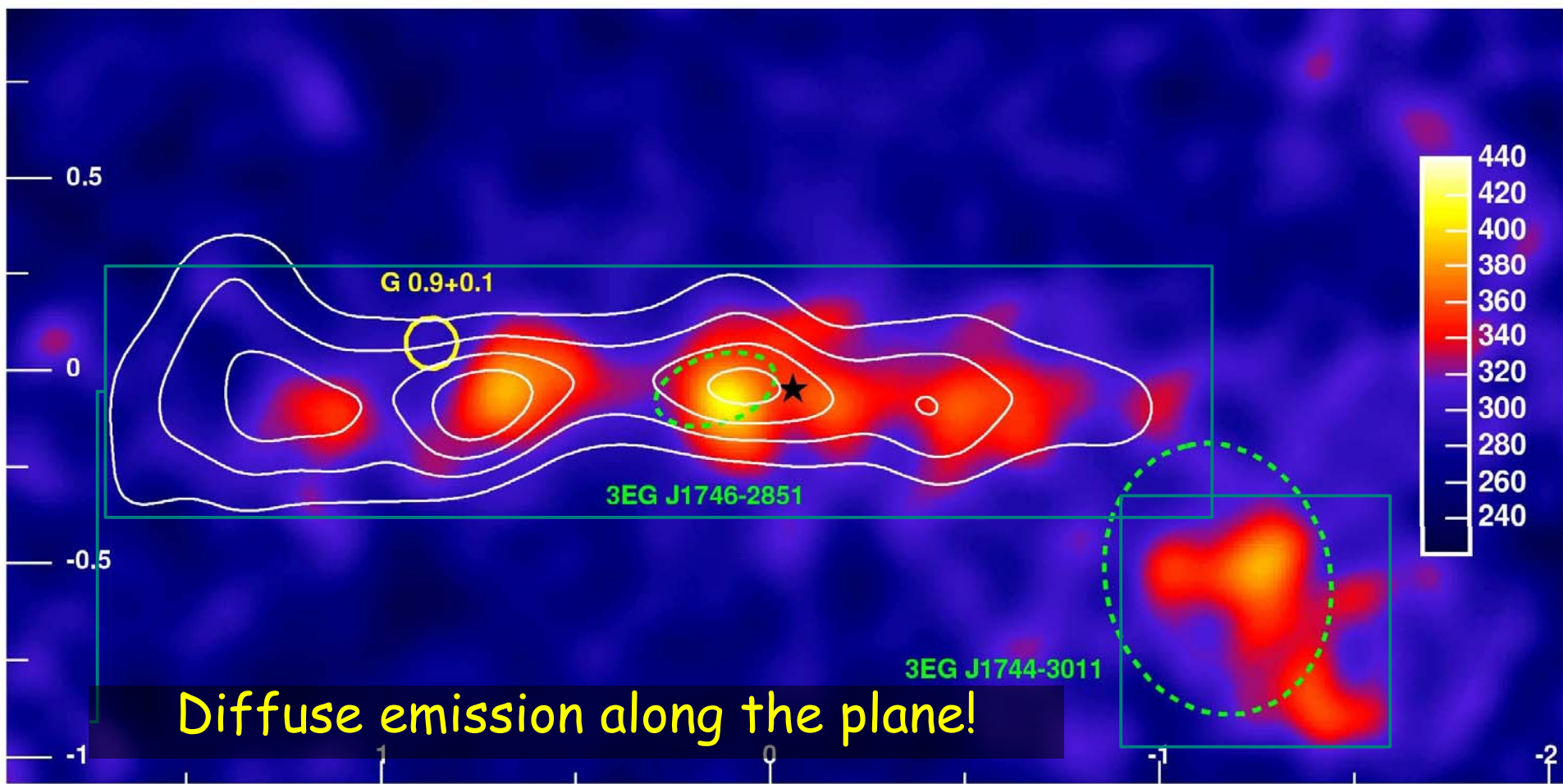


Need to subtract the two bright sources





# Residuals after source subtraction



btw: new source HESS J1745-303





# Integrated Latitude Slice

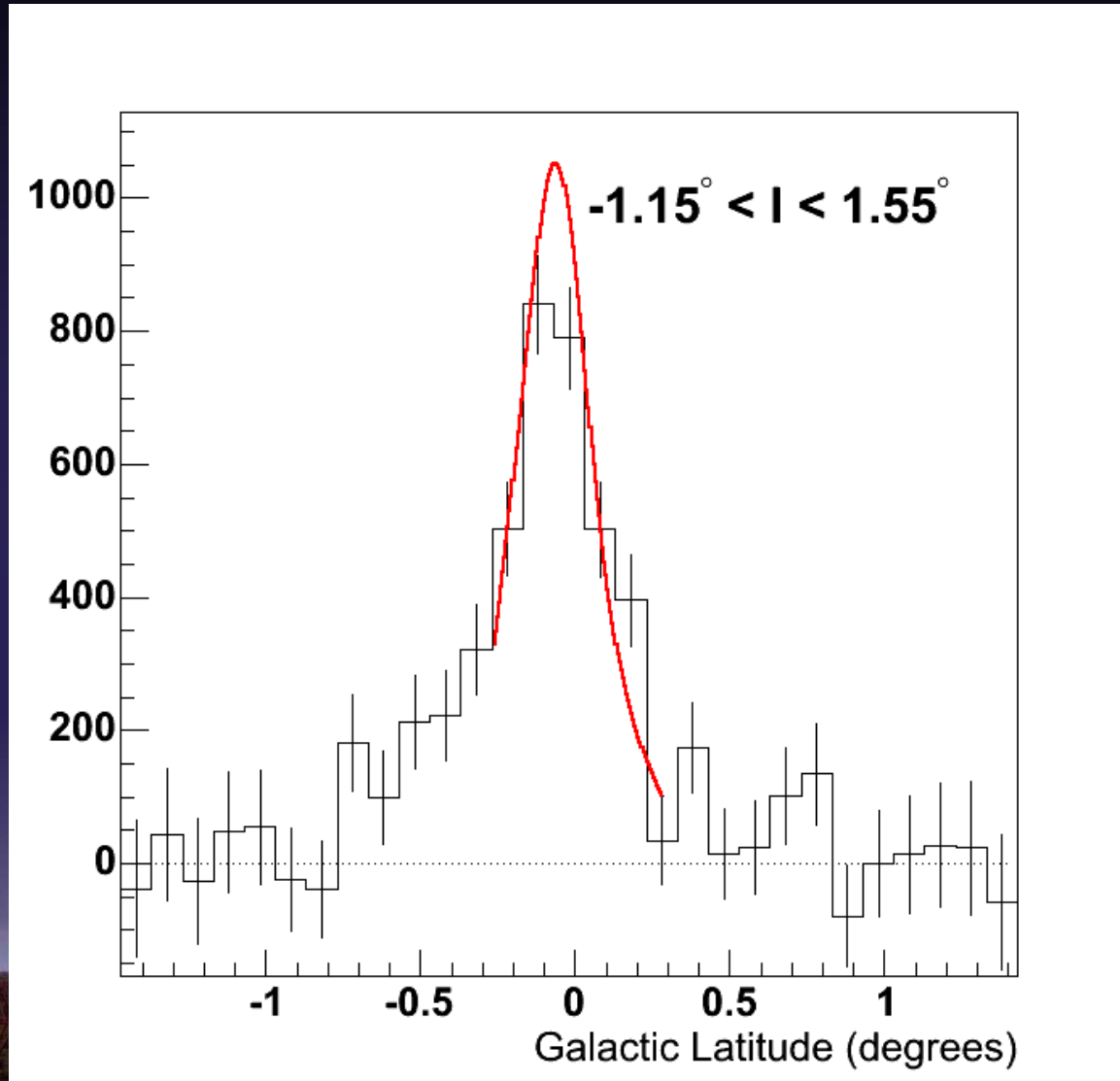
Reasonable  
agreement in  
the region  
covered by CS  
measurements

Close to a  
Gaussian with  
 $0.2^\circ$  RMS

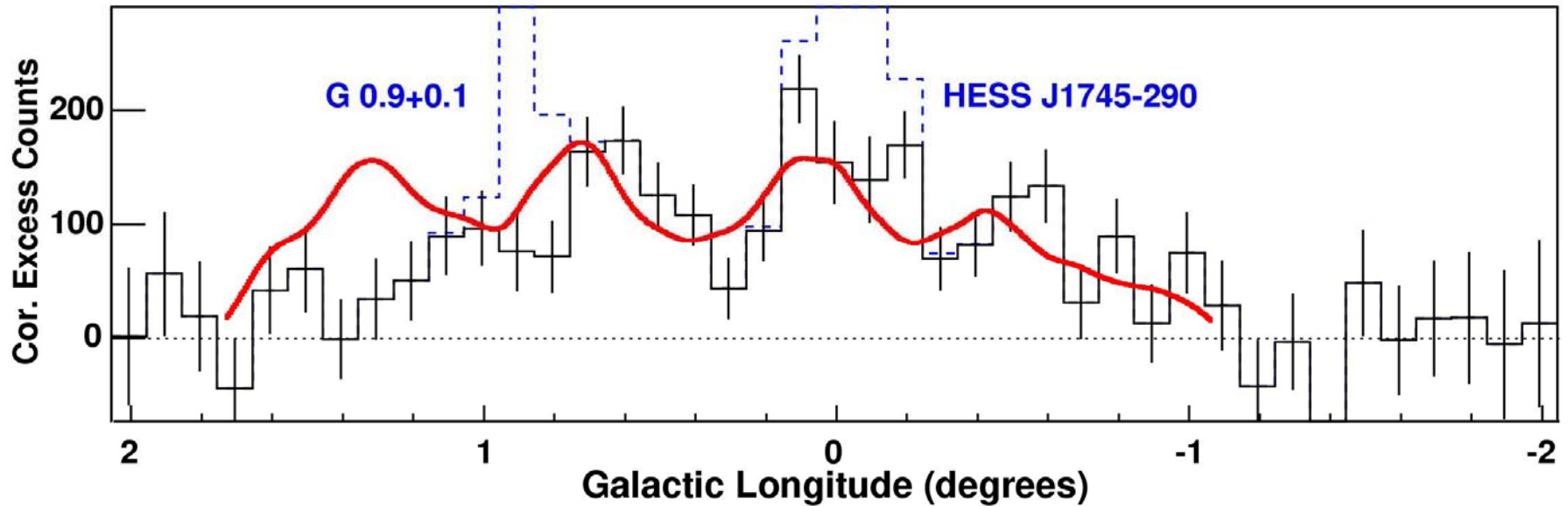
CF PSF  $< 0.1^\circ$

Equivalent to  $\sim 30$   
parsecs

$14.6 \sigma$  signal



# Longitudinal Slice

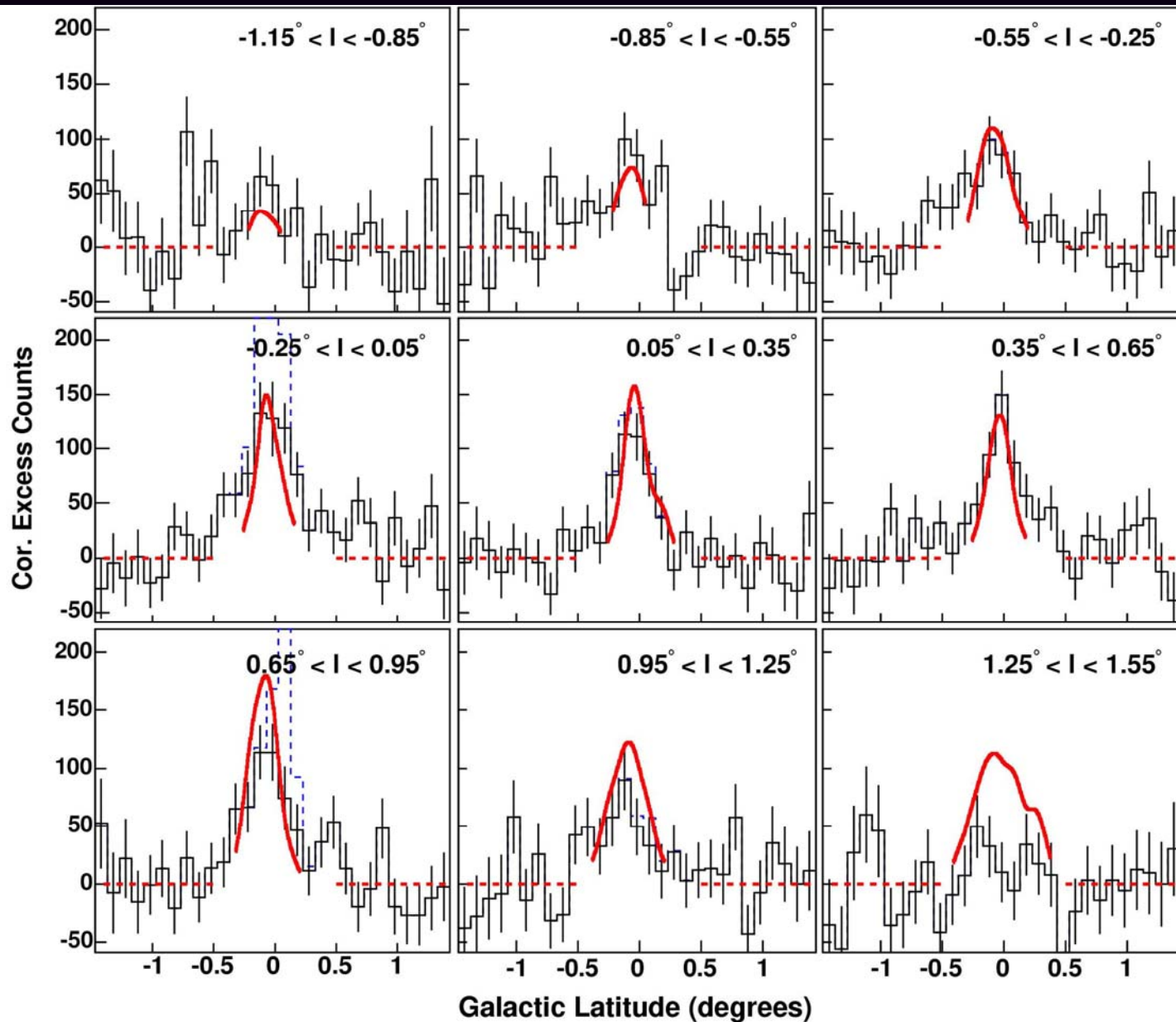


Reasonable overall agreement

but: deficit around  $l = 1.3^\circ$



...and in the longitude bands





# Energy Spectrum

## Expectations

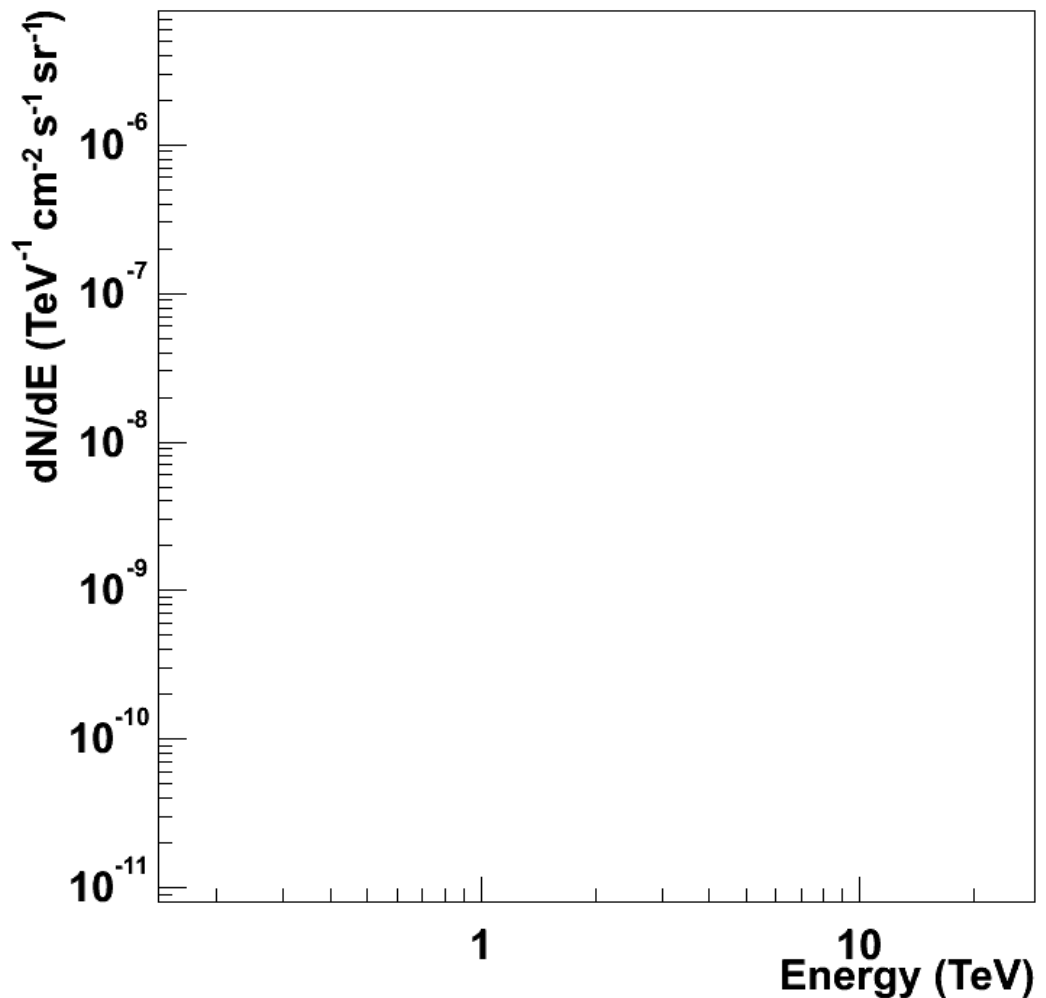
Molecular target material  
is  $3\text{--}8 \times 10^7 M_{\text{sun}}$  (Tsuboi -  
CS, SCUBA:  $4\text{--}6 \times 10^6 M_{\text{sun}}$ )

Distance  $\sim 8.5$  kpc

Cosmic Ray density?

Assume Local

$\pi^0$  decay flux...



# Energy Spectrum

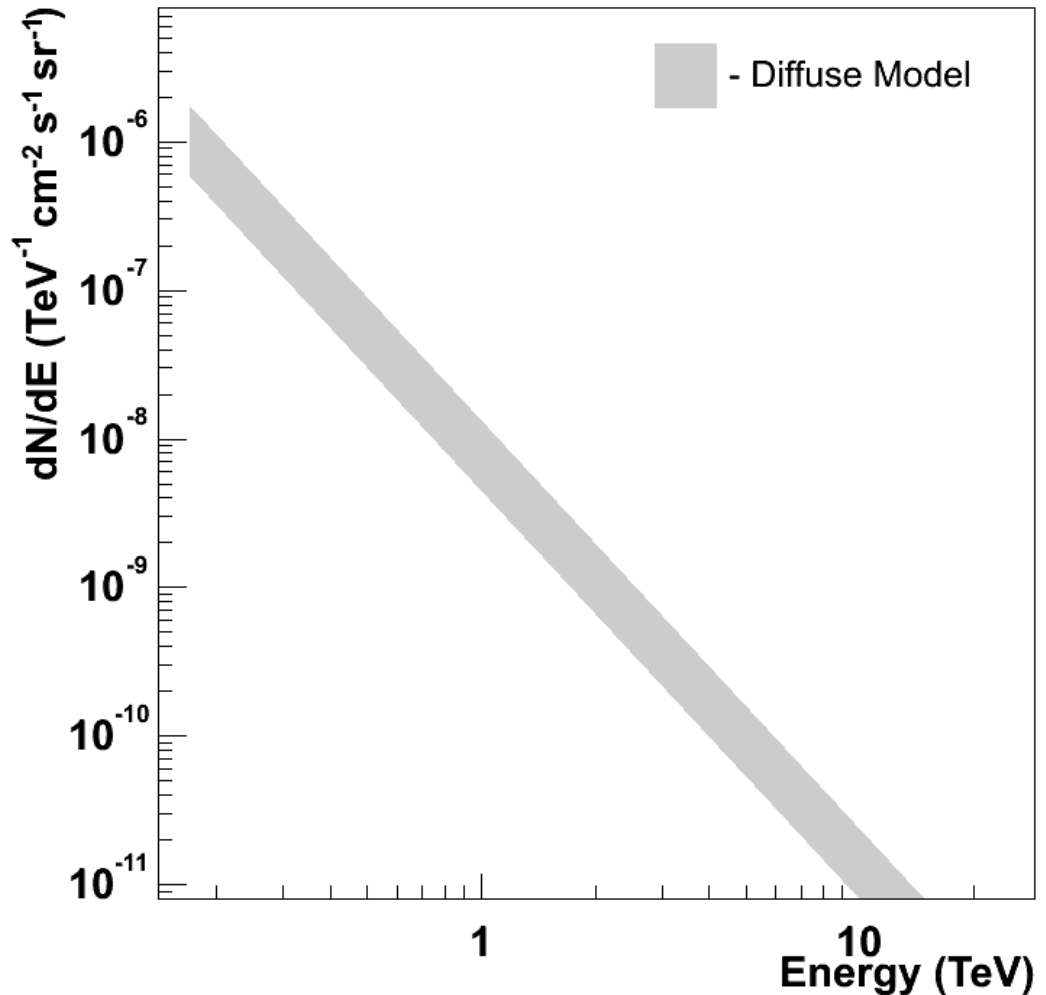
## Gamma Flux:

$$J(> E) \approx 1.5 \times 10^{-13} \\ (E/1\text{TeV})^{1.75} (M_5/d_{\text{kpc}}^2) \\ \text{photons cm}^2 \text{s}^{-1}$$

(a la Aharonian 1991)

Index:  $\Gamma_\gamma \sim \Gamma_{\text{XP}}$

For  $M_5 = 300 - 800$



# Energy Spectrum

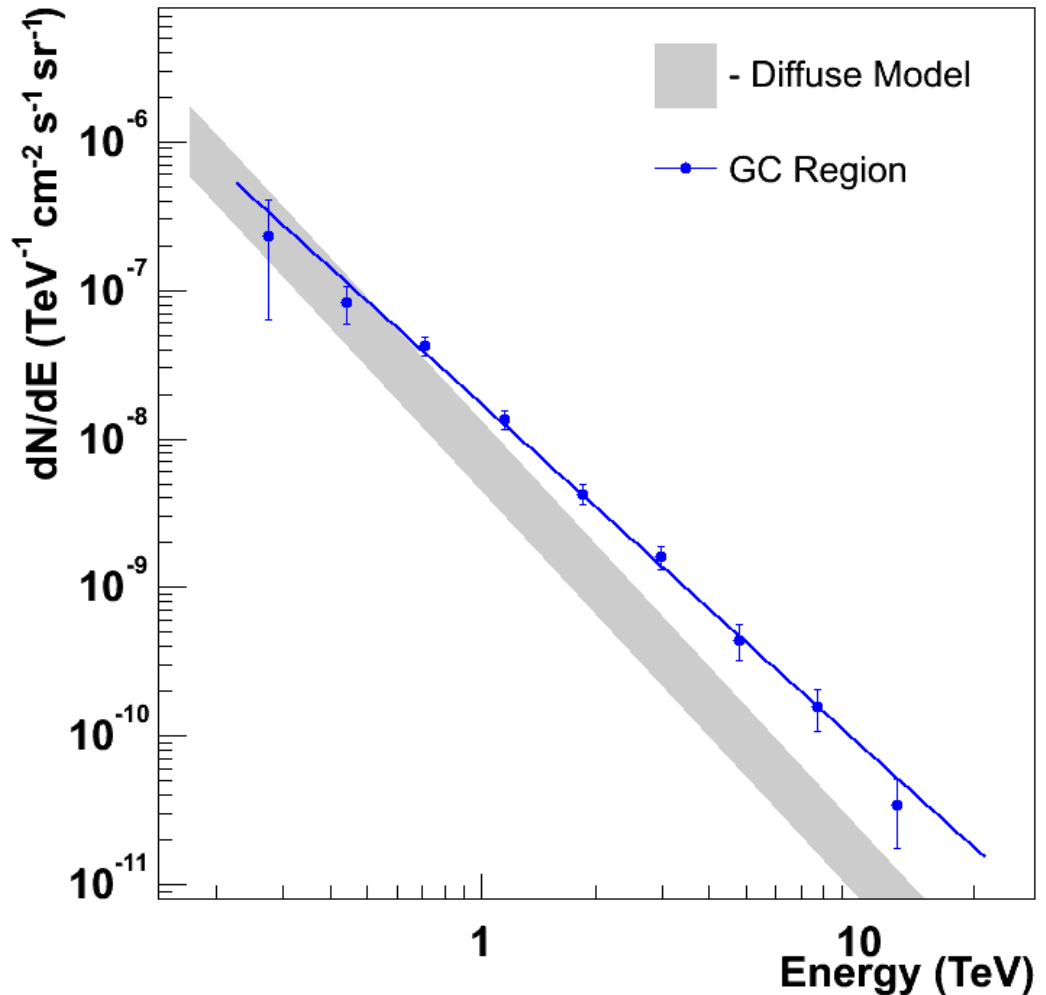
## Measured Diffuse Spectrum

$$\Gamma_{\gamma} = 2.29 \pm 0.07_{\text{stat}} \pm 0.20_{\text{sys}}$$

Flux > 1 TeV:

$$3.1 \pm 0.3 \times 10^{12}$$

$$\text{cm}^{-2} \text{ s}^{-1} (13\% \text{ Crab})$$





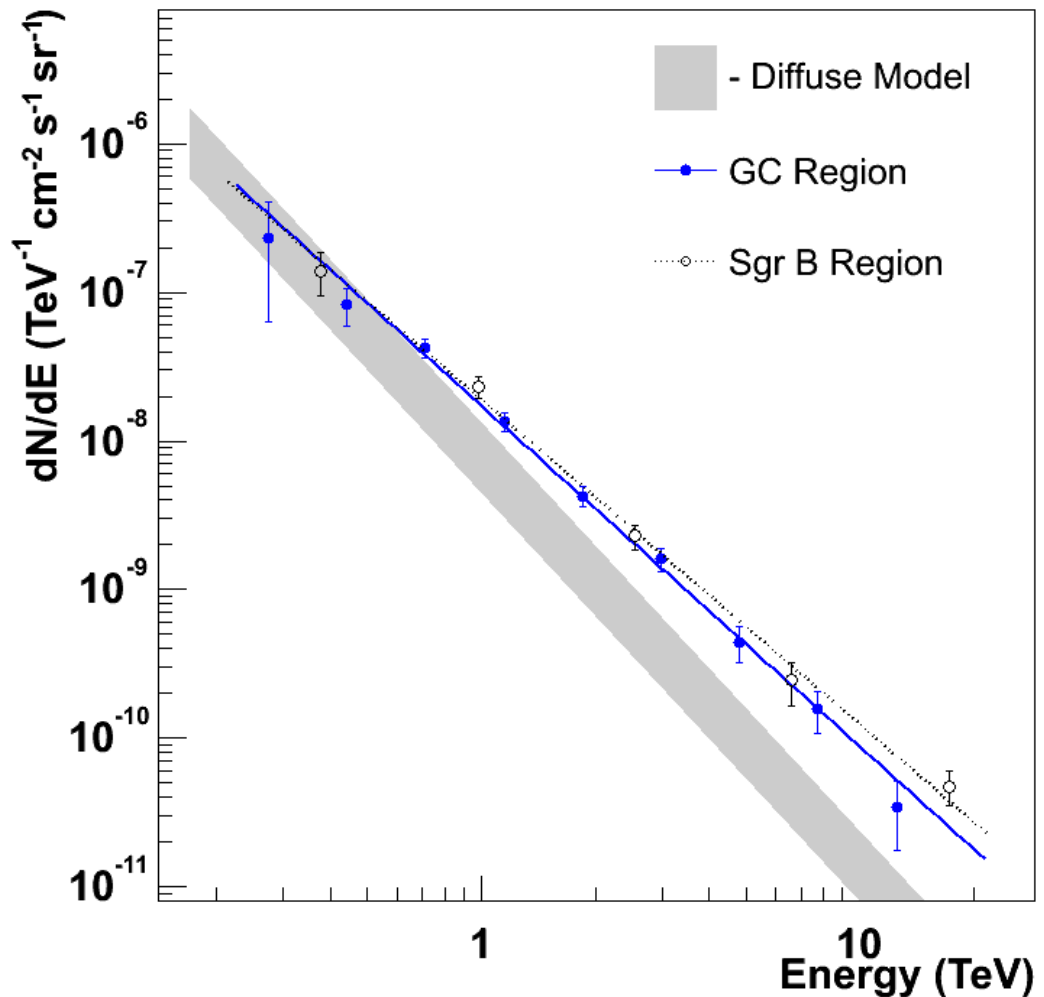
# Energy Spectrum

## Sgr B region

$$\Gamma_{\gamma} = 2.1 \pm 0.2_{\text{stat}} \pm 0.2_{\text{sys}}$$

Flux > 1 TeV:

$$1.2 \pm 0.2 \times 10^{12} \text{ cm}^{-2} \text{ s}^{-1} \text{ (5\% Crab)}$$



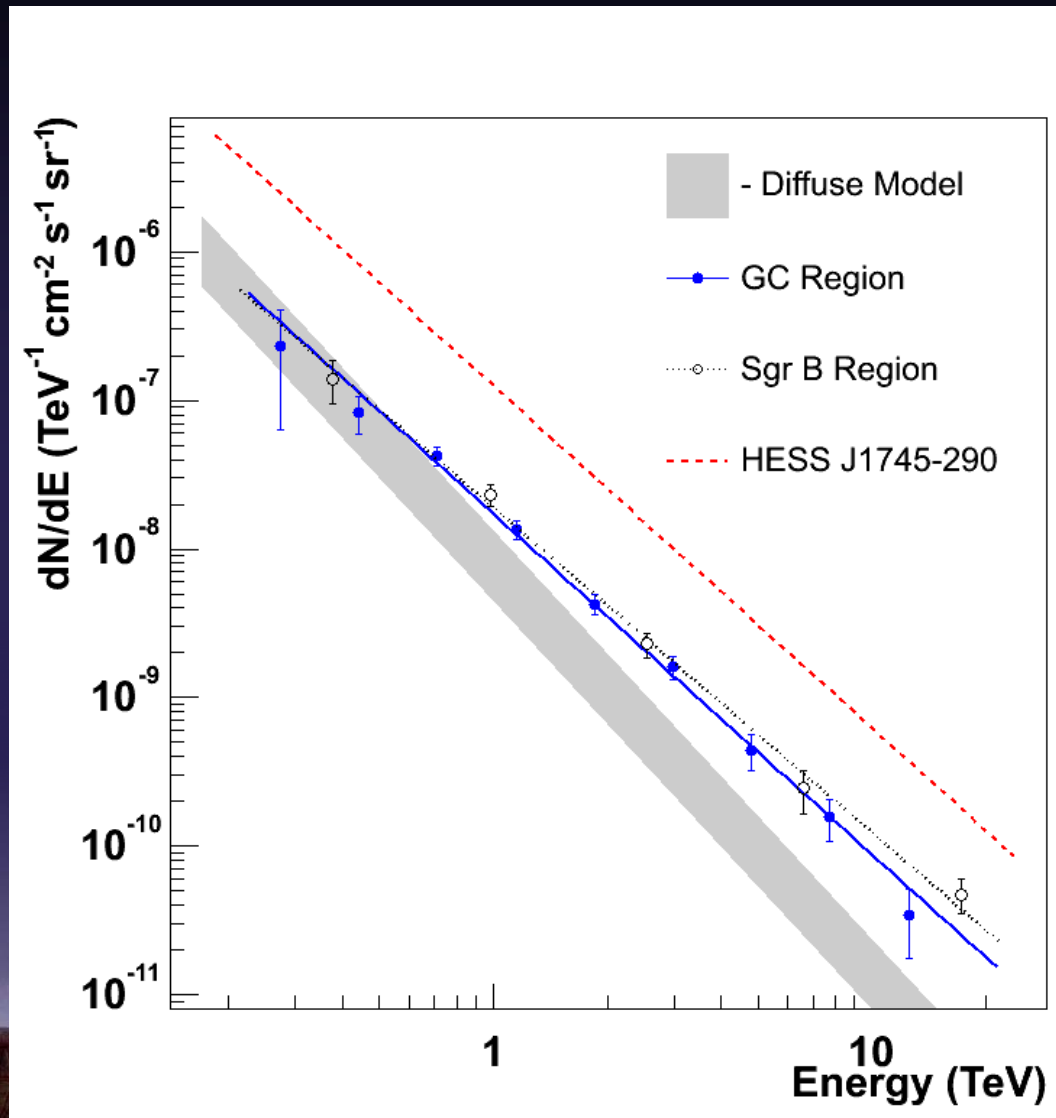
# Energy Spectrum

The Galactic Centre  
Source: HESS  
J1745-290

(solid angle is  
integration radius  
used - source looks  
point-like)

All emission in the  
GC has

$$\Gamma_{\gamma} \approx 2.2$$



# Interpretation

Several possibilities exist

Emission is a superposition of many individual 'active' gamma-ray sources, but

- ✗ Close correlation with molecular material
- ✗ Need many ( $\sim 7$ ) unknown sources eg SNRs and/or pulsar

Or diffuse emission, caused by CR interactions

High energy CR density enhanced in the GC ?

- 1) Additional CRs are accelerated by a population of sources in the region
  - 2) A single source (HESS J1745-290) accelerated most high energy ( $> 10$  TeV) CRs in the central 200 parsecs
- ✓ Same spectral index

✓ Deficit in emission around  $l = 1.3^\circ$

